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WATER-LOSS INVESTIGATIONS: LAKE HEFNER 1958 EVAPORATION REDUCTION INVESTIGATIONS

Lake Hefner Evaporation Reduction
Investigations
Oklahoma City, Oklahoma

June 1959

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Water-Loss Investigations:
Lake Hefner 1958
Evaporation Reduction Investigations

REPORT BY THE COLLABORATORS

City of Oklahoma City, Oklahoma

Oklahoma State Department of Health

U. S. Department of Health, Education and Welfare
Public Health Service

U. S. Department of Commerce
Weather Bureau

U. S. Department of the Interior
Geological Survey
Bureau of Reclamation

JUNE 1959

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EVAPORATION REDUCTION INVESTIGATIONS
LAKE HEFNER, OKLAHOMA CITY, OKLAHOMA
of
1958

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FOREWORD

by
Grant Bloodgood, Chairman
Committee of Collaborators
Lake Hefner Evaporation Reduction Investigations

The Lake Hefner evaporation reduction investigation was a truly cooperative effort towards which a large number of agencies and individuals contributed. This cooperation on the part of the collaborators made it possible to conduct in a comprehensive and thorough manner an evaluation of the practical feasibility of treatment of a water surface with a monomolecular layer for the purpose of reducing the loss of water by evaporation and of the hydrologic, the water quality, public health, and economic aspects of such a treatment. The functions of the organizations participating in the Committee of Collaborators were as follows:

1. U. S. Bureau of Reclamation--To apply the monolayer, to determine the extent of coverage and condition of the film, to estimate the evaporation savings based on coverage and temperature correlation, and to make an economic evaluation of the treatment.

2. U. S. Geological Survey--To collect the water and energy-budget data and to compute natural and treated evaporation to determine the evaporation savings.

3. City of Oklahoma City--To make biology, limnology, and water quality studies.

4. U. S. Public Health Service--To test and clear materials proposed for use at Lake Hefner and to study the possible changes in water quality resulting from the treatments.

5. U. S. Weather Bureau--To supply necessary climatological data and to prepare special weather forecasts for the tests.

6. Oklahoma State Department of Health--To keep in touch with the progress of of the work with special reference to any possible public health aspects of the investigation.

In addition to the Committee of Collaborators, very significant contributions to the conduct of the Lake Hefner investigation were made by the Denver Board of Water Commissioners, who collaborated in the performance of field tests on attrition losses at Ralston Creek Reservoir, a part of the Denver municipal water supply system to be described subsequently in this report; by the Northern Colorado Water Conservancy District and the City of Loveland, Colorado, who participated in the tests of techniques of application and in other monomolecular layer investigations conducted at Rattlesnake Reservoir and Carter Lake in Colorado; by the 3415th Technical Training Wing, Lowry Air Force Base, Denver, Colorado, who performed the pioneering work in aerial photography of a monomolecular layer as applied to Carter Lake Reservoir; by the Photographic Section of the Tinker Air Force Base, Oklahoma City, Oklahoma, who took aerial photographs of Lake Hefner; and by the Wildlife Research Laboratory of the Fish and Wildlife Service's Bureau of Sports Fisheries and Wildlife, who conducted a limited investigation on the effects of hexadecanol on wildlife at Lake Hefner. The collaboration of numerous representatives of the industries and the contribution made by a great number of unnamed individuals and organizations who made possible the execution of the investigation through their help in procurement, equipment development, and operations and maintenance aspects of this complex investigation is acknowledged.

It was agreed at the June 6, 1958 committee meeting held at Oklahoma City, Oklahoma, that none of the collaborating agencies would make piecemeal releases of the results of their findings. This was done because of the unpredictable directions, in the absence of any precedents whatsoever, in which the experiment might turn. This was a wise agreement, as at numerous stages in the investigation, completely erroneous and damaging conclusions could have been drawn by those not having access to all of the data, or personal experience on the lake. By not disclosing the results of their work until the December 18 meeting, a single, clear, and accurate picture of the results of the 1958 Lake Hefner tests has resulted. Thus, this final report on the 1958 Lake Hefner evaporation reduction investigations presents in detail the findings of the collaborators which were given in summary form at the brief meeting held in Denver, Colorado, on December 18, 1958. Following mutual review of the chapters, the Joint Statement dated May 12, 1959, was agreed to by the collaborators.

In view of the tremendous volumes of original data, transcriptions, and tabulation, it did not seem desirable to include them in this report, although this was considered earlier in this study. It is recommended that the reader interested in learning more details about the investigations conducted by any of the collaborating agencies correspond directly with that organization.

May 12, 1959

JOINT STATEMENT OF COMMITTEE OF COLLABORATORS

It has been demonstrated by the Bureau of Reclamation that techniques are available to cover the 2,500-acre Lake Hefner with a fully compressed monolayer of hexadecanol, given favorable conditions. The Geological Survey obtained the data needed to evaluate the success of the film in suppressing evaporation. Techniques developed as a result of research in recent years were used to measure the actual evaporation and to compute the evaporation that would have occurred if no film had been applied. The Geological Survey's evaluation showed that during the period of treatments, July 7--October 1, 1958, it was possible to achieve an overall reduction in evaporation of slightly more than 9 percent, although weather conditions were not favorable for maintaining the film.

It has been demonstrated that the effectiveness of evaporation retardants is lessened at higher temperatures and the 9 percent reduction achieved is about one-fourth of the potential reduction with the kind of material used at Lake Hefner and at the water temperatures experienced. The water savings by evaporation reduction at Lake Hefner were accomplished at a total cost for labor and hexadecanol approximately equal to the total value of the untreated water saved to Oklahoma City.

No hexadecanol could be detected by the Public Health Service in water reaching the inlet of the Oklahoma City water supply. Oklahoma City officials found that concentrations of micro-organisms normally present in lake waters increased markedly as a result of feeding on the hexadecanol. However, the purified water met Public Health Service drinking water standards.

The wind has a very pronounced effect on the behavior of the film. With wind velocities greater than about 20 mph, it was found impractical to maintain a film on Lake Hefner.

It may be expected that under an operational program with improved procedures and materials, the costs of evaporation reduction would be considerably less than experienced in the Lake Hefner trial.

LAKE HEFNER FINAL REPORT OF 1958

INTRODUCTION

by
Walter U. Garstka

Over half a century was to pass between the time of the discovery and identification of a laboratory curiosity called a monomolecular film and the time when the use of such films would be attempted in large-scale field applications for practical economic purposes. Since 1891, when Agnes Pockles studied the characteristics of oil films spreading on water surfaces, many scientists have studied the physical and chemical properties of oil films as well as monolayers formed from other liquids and solids placed on fluid surfaces by various methods. 7/* Among the many well known scientists contributing valuable information to the knowledge of monolayers are Lord Rayleigh, Dr. I. Langmuir, and Dr. V. J. Schaefer. 8/, 4/ A comprehensive review of the control of evaporation losses from reservoirs, together with an evaluation of the magnitude of the problem and the importance of the work is presented by Eaton. 2/

In recent years the increasing demand on available water supplies all over the world has focused attention on the possible use of monomolecular films to conserve this valuable and essential resource. Consequently, many organizations and individuals started almost simultaneous laboratory and field programs to determine the economic feasibility of such an application of monolayers.

While reviewing Miss Pockles' work, Lord Rayleigh, in 1899, concluded that the film of certain chemicals spread on water surfaces was only one molecule thick. These films were called monomolecular layers or monolayers. During the 1920's, work by du Noüy, Rideal, and the Langmuirs indicated that monomolecular films of many chemical compounds could reduce evaporation from water surfaces to varying degrees. 1/, 9/, 3/ Continuing research, conducted for the most part by Sebba, Briscoe, Langmuir, and Schaefer during the early 1940's, revealed that the long chain alcohol, hexadecanol, was one of the most effecient chemicals known for reducing evaporation from water surfaces in laboratory tests. 10/, 5/

In 1952, the Bureau of Reclamation began to consider the feasibility of applying monomolecular films to large reservoirs for water conservation. In 1955, a laboratory and field study of this problem was undertaken. At about the same times, similar research programs were initiated by several organizations in the United States and in Australia and Africa. In fact, the first field application of a monomolecular layer for reservoir evaporation reduction loss was that performed in 1953 by Mansfield, an Australian physical chemist. 6/ Each of these countries faces critical water shortages during at least part of each year. In the United States, the Geological Survey has also

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*Numbers marked thus, _/ refer to references which are listed at the end of each chapter.

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been working in cooperation with the Southwest Research Institute in a field and laboratory research program directed at a solution of this problem.

After an initial literature search and preliminary laboratory tests indicated that the method had possibilities, the Bureau of Reclamation embarked upon a two-phase program. One phase was a general investigation of the physics, chemistry, and engineering aspects of the use of monomolecular layers for reservoir evaporation reduction. The other phase was to take hexadecanol as a typical material and conduct a series of tests culminating with a field test on a large reservoir. Hexadecanol, also known as cetyl alcohol, was chosen because laboratory tests had confirmed the findings of previous investigators that, at that time, 1955, this was the most promising material. The requirements of the second phase often were such that the two phases merged into one specific activity.

Associated with the use of monolayers on large reservoirs and field tests of this technique are many important elements covering a wide range of scientific engineering and operational fields. Some of these are the application and maintenance of the film, the influence of field conditions on the film and its performance, the economic aspects, measurement of actual evaporation and determination of no-film evaporation, water quality, lake biology, and various possible public health aspects. It soon became apparent that a program of such a wide scope could best be conducted by a group of collaborating organizations each having not only vast experience in one of the many required activities of the study, but also a vital interest in reservoir evaporation reduction. Therefore, a cooperative effort for the field test of hexadecanol was organized.

Many reservoirs were considered as being possibly suited for large-scale field tests. Lake Hefner, a municipal water supply reservoir about 2,500 acres in area and a part of the water supply system for Oklahoma City, Oklahoma, was picked for the field tests because of several factors--its size, geographic location, the meteorologic conditions existing there during the summer and early fall months, and probably most significantly, the fact that a detailed water budget including evaporation losses had been determined for this lake by several cooperating organizations in 1950-51, 11/ demonstrating the feasibility of conducting accurate evaporation studies at the lake.

After the decision to conduct the large-scale field tests at Lake Hefner, it was deemed advisable to perform preliminary tests at Kids Lake, an arm of Lake Hefner which had been closed off from the main body of water and was hydrologically independent of Lake Hefner.

The tests were conducted at Kids Lake to learn if there would be any adverse effects on water quality such as to preclude the consideration of Lake Hefner for the evaporation reduction tests with hexadecanol. This was necessary because Lake Hefner is part of the City of Oklahoma City municipal water supply.

A "Committee of Collaborators" was formed to act as an advisory committee in making the studies at Kids Lake and Lake Hefner. This committee, for the Kids Lake investigations, was composed of representatives from the U. S. Bureau of Reclamation, the City of Oklahoma City, the Oklahoma State Health Department, the U. S. Public Health Service, and the U. S. Geological Survey. The function of the committee was to coordinate the proposed tests so that a maximum of information could be secured.

Results of the Kids Lake tests indicated that the methods for dispensing materials, maintaining a monolayer, and detecting and evaluating a monolayer were major problems that would have to be solved before the Lake Hefner tests could be started. Results of the studies conducted at Kids Lake in 1956 are included in this report as Part I of the Appendix.

During the 2 years between the time of the Kids Lake tests and the initiation of the Lake Hefner tests in the spring of 1958, tests were made by the Bureau of Reclamation in its Denver laboratories and at Rattlesnake, Ralston Creek, and Carter Lake Reservoirs near Denver to solve these monolayer dispensing and detecting problems. These tests are described in Appendices II-A and II-B.

From the beginning of the screening tests in 1956, it had been indicated that the efficiency of some of the monomolecular films in reducing evaporation from water surfaces was dependent upon ambient temperature conditions. During the winter of 1956 and 1957, an attempt was made to establish this efficiency-temperature correlation by tests conducted in calorimeter rooms where the air temperature could be held constant and where the humidity was very nearly constant. These tests were unsuccessful, probably due to contamination of the test pans by the unfiltered air that was circulated through the rooms. During the period from May through October of 1958, concurrently with the Lake Hefner tests, a series of outdoor tests was conducted on 22 different combinations of fatty alcohols, including the hexadecanol preparation used for the Lake Hefner tests, to determine this efficiency-temperature correlation. Such a correlation was required for the commercial grade of hexadecanol used at Lake Hefner in estimating the evaporation reduction effected by the treatment. These tests indicated that there are various commercial grades of the long chain alcohols and combinations of these alcohols that would be more efficient than the material chosen for the Lake Hefner tests for the air and water temperatures that prevailed during these tests. Results of these temperature correlations are shown in Appendix II-C.

The Lake Hefner tests were so organized that each participating organization was responsible for a specific study. Analysis of data following the tests was made by each group without knowledge of the others' results. On December 18, 1958, a meeting was held at which each group gave a preliminary report on the results of its phase of the tests. In this, the final report on the 1958 Lake Hefner tests, the results of each phase of the studies are shown as a separate section as prepared by the responsible organization.

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LAKE HEFNER TESTS

EVALUATION OF EVAPORATION SUPPRESSION AT LAKE HEFNER

By G. Earl Harbeck, Jr.

U. S. Department of the Interior
Geological Survey

EVALUATION OF EVAPORATION SUPPRESSION AT LAKE HEFNER

Lake Hefner was chosen for the evaporation research conducted in 1950-51 and for the evaporation suppression tests in 1958 primarily because it is one of the few reservoirs in the United States where evaporation can be determined accurately by the water-budget method. In the present study, measurement of the actual evaporation from Lake Hefner was not sufficient; of equal importance was the determination of the evaporation that would have occurred if a monomolecular film had not been applied.

Theory

It might appear that the success of the treatment could be evaluated through the use of an evaporimeter. At Lake Hefner this could have been accomplished by obtaining records of pan evaporation and lake evaporation during a pretreatment calibration period in order to determine the ratio of lake evaporation to pan evaporation, commonly called the pan coefficient. It would then be necessary to assume that the pan coefficient thus determined is applicable after the film is placed on the reservoir. The validity of this assumption is questionable. During the earlier Lake Hefner studies (Kohler, 1954) 16/ it was found that the class-A pan coefficient increased from 0.35 in May to 1.32 in November. Thus an evaluation scheme based upon an assumed constant pan coefficient does not appear defensible.

Another method requires the use of two lakes or reservoirs. It is preferable that they be as much alike as possible in most physical characteristics. During one summer one lake is treated and its change in stage compared with that of the other lake, which is considered to be the control. The next summer the procedure is reversed. Thus it is possible to account for any inherent physical difference between the two lakes, such as seepage losses. On statistical grounds, this technique has much to recommend it. Its disadvantages are that two lakes are required and that two summers are needed for the study.

A technique has been developed to permit evaluating the reduction in evaporation by utilizing certain mass transfer and energy budget concepts (Harbeck and Koberg, 1959) 15/. A complete description of the theory is beyond the scope of this report. Basically, however, the method involves the assumption that the monomolecular film has no effect on the net solar and atmospheric radiation received, nor on the amount of energy brought into the lake in inflow or taken out in outflow. It is also assumed that the seasonal change in energy stored in the lake is not affected by the film.

The film does affect certain items in the energy budget. If the film successfully suppresses evaporation, the energy normally utilized for evaporation must be disposed of in some other manner. The water surface temperature must rise until the energy no longer being used for evaporation is being returned to the atmosphere by other processes, principally back radiation from the water surface and conduction. The equation is as follows:

$$0.970\sigma\left[(T_o' + 273)^4 - (T_o + 273)^4\right] + \left[\rho E'L - N u (e_o - e_a)\right] + K u (T_o' - T_o) = 0 \qquad (1)$$

in which σ = Stefan-Boltzman constant for black-body radiation

(= 1.171×10^{-7} cal cm^{-2} deg^{-4} day^{-1})

T_o' = observed water-surface temperature in °C.

T_o = water-surface temperature in °C. that would have been observed if film had not been applied

ρ = density of evaporated water (= 1 cal gm^{-1} deg^{-1})

E' = observed evaporation in gm cm^{-2} day^{-1} (= cm day^{-1})

L' = latent heat of vaporization at T_o'

N = an empirical constant

u = wind speed at intake tower in knots

e_o = saturation vapor pressure at T_o in mb

e_a = vapor pressure of the air in mb

K = an empirical constant

The values of empirical constants N and K are determined during the pretreatment calibration period using equations derived from basic heat-and-mass-transfer theory. The only unknown in equation (1) is T_o, as e_o is explicitly determined by T_o. Because the relation between T_o and e_o is not linear, a direct solution of equation (1) is impractical, and it is simpler to assume successive values of T_o until equation (1) balances. Then E, the evaporation that would have occurred if no film had been present, can be computed from

$$E = \frac{N u (e_o - e_a)}{L} \qquad (2)$$

Equations (1) and (2) are in effect two simultaneous equations which provide a means of solving for the two unknowns, E and T_o.

Instrumentation and Methods

The instrumentation used for the determination of water-budget evaporation was essentially the same as used in the earlier studies (Harbeck and Kennon, 1954) 14/, with some modifications. The 22-gage network of rain gages was not reestablished. Instead, rainfall on the lake surface was computed from the rise in lake level as indicated by the four stage gages (Harbeck and Coffay, 1959) 13/. Another raw waterline from the lake to the filter plant has been installed since the earlier studies; the new Venturi meter was calibrated volumetrically by Bureau of Reclamation engineers. In most other respects, items in the water budget were determined as described in the earlier report (Harbeck and Kennon, 1954) 14/, and the methods used will not be described here. The figures of daily evaporation were adjusted for thermal expansion of the lake.

Radiation equipment, which was installed on top of the intake tower at the north end of the lake, included a total hemispherical radiometer and pyrheliometer (see Figure 1). Other items of meteorological equipment at the intake tower were an anemometer and a copper-constantan thermocouple psychrometer, and a thermocouple for measuring water-surface temperature. The outputs of the radiation and temperature equipment were recorded on a multichannel self-balancing Brown potentiometer. Records of water-surface temperature were obtained at three other places on the lake with weekly temperature recorders mounted on rafts.

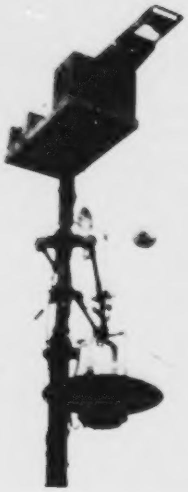

Figure 1.--Total hemispherical radiometer, thermocouple psychrometer, and anemometer on mast on top of intake tower at Lake Hefner. Photograph by C. R. Daum.

Thermal surveys of the lake were made each Monday and Thursday, if the lake was not too rough. A Whitney underwater thermometer was used to determine the variation of temperature with depth at the same 16 stations used in the earlier Lake Hefner studies (Anderson, 1954) 12/.

Comparison Between Energy-budget and Water-budget Evaporation

Evaporation from Lake Hefner was computed using both the energy-budget and water-budget methods for the period May 18 to October 30, 1958. Because of the uncertainties involved in determining changes in energy storage for shorter periods of time, energy-budget evaporation was computed for periods averaging about 10 days in length, even though thermal surveys were made at shorter intervals. A comparison of energy-budget and water-budget results indicated good agreement except during the last half of June. Rainfall records indicate that more than 8 inches of rain fell during this period. The amount of surface inflow to the lake from the natural drainage area was uncertain, and the water-budget data were considered unreliable and were discarded. Because of possible errors in the advected energy item during this period, the energy-budget results were not considered very reliable. During the period August 28 to September 2, 1958, the radiation recorder did not operate properly, and the energy budget could not be computed. For the remaining periods, the comparison between the energy budget and the water budget is given in the following table.

Table 2.--Daily Evaporation From Lake Hefner by Water-Budget Method.
(In acre-feet)

Day	1958					
	May	June	July	Aug	Sept	Oct
1		35.0	21.6	41.6	63.9	70.7
2		39.8	46.6	12.7	72.0	82.5
3		49.3	64.3	39.1	80.7	39.7
4		53.7	54.7	56.3	72.6	29.6
5		38.2	61.9	70.2	35.4	34.5
6		82.7	27.3	85.9	46.3	18.5
7		78.1	41.[illegible]	69.6	25.5	0.8
8		130.6	39.3	79.5	21.6	3.3
9		50.6	42.9	16.5	64.2	18.5
10		46.5	58.6	42.3	31.1	85.6
11		21.8	64.6	56.8	23.4	63.1
12		85.2	79.6	46.5	21.9	31.8
13		77.9	70.3	29.9	66.4	36.3
14		64.9	91.9	32.4	77.3	30.3
15		34.1	24.3	66.1	12.2	14.0
16		23.2	40.3	49.4	36.8	19.9
17		*29.7	79.5	52.0	106.7	11.4
18	19.1	*43.8	74.6	29.1	35.0	16.3
19	30.7	*44.2	98.1	73.2	24.3	40.9
20	44.2	*25.1	59.1	49.5	17.0	51.3
21	58.4	*55.5	31.8	63.5	11.6	66.8
22	51.2	*37.6	31.9	41.5	22.1	42.4
23	8.2	*43.8	49.8	45.7	4.8	63.3
24	59.4	*54.8	65.0	54.2	22.9	28.2
25	45.1	*109.5	41.2	40.8	8.0	36.1
26	46.9	*66.1	31.8	25.9	18.0	42.8
27	40.5	*49.2	83.0	63.9	107.3	51.6
28	52.7	*70.8	4.3	47.1	48.6	7.6
29	37.1	*57.1	37.6	96.4	65.8	57.7
30	77.9	*45.7	97.1	92.4	111.0	31.5
31	49.7		50.5	37.3		43.8
Total	621.1	1,644.5	1,664.9	1,607.3	1,354.4	1,170.8

*Computed using mass-transfer formula

Table 1.--Comparison between energy-budget and water-budget methods of determining evaporation from Lake Hefner.

Period	Evaporation (acre-feet)	
	Water budget	Energy budget
1958		
May 21 (8:30 a.m.) to June 16 (6:50 a.m.)	1,404	1,376
July 7 (7:15 a.m.) to Aug. 28 (6:45 a.m.)	2,740	2,774
Sept. 8 (6:30 a.m.) to Oct. 2 (7:05 a.m.)	1,044	992
Total	5,188	5,142

The totals agree within 1 percent, although for the periods listed the maximum difference was approximately 5 percent. The remarkably close agreement between the totals is doubtless partly coincidental; the only conclusion to be drawn is that either result is of acceptable accuracy. The energy-budget data do not permit as much flexibility as do the water-budget data for analytical purposes, for the energy-budget results are for periods of about 10 days. Accordingly, the energy-budget results were considered to be only corroborative evidence of the accuracy of the water budget, and were not used in any of the subsequent analyses.

It was considered desirable that the record of daily evaporation for the period May 18 to October 31 be complete. As neither the water budget nor energy budget was considered reliable during the last half of June, daily estimates were made using a mass-transfer equation of the type

$$E = N u (e_o - e_a) \qquad (3)$$

In the Lake Hefner report (Marciano and Harbeck, 1954, p. 67) 17/, an equation of this type was given. The data used were wind speed and vapor pressure at the airport station of the Weather Bureau and water surface temperature at Lake Hefner. The value of the coefficient N, when adjusted for the change since 1951 in recording wind speed in knots instead of miles per hour, is 0.00204. For the periods May 18 to June 16, July 1-6, and October 1-31, airport wind speeds and vapor pressures, recorded water-surface temperatures at Lake Hefner, and water-budget evaporation resulted in a computed value of N exactly the same as that obtained in the 1950-51 studies. It is known that the position of some of the instruments at the airport was changed since 1951, and it could not be assumed that the old value of N was applicable. Using equation (3), daily evaporation from Lake Hefner was computed for the period June 16-30. The figures of daily evaporation for the period May 18 to October 31 are given in Table 2.

It would have been desirable to compute evaporation from Lake Hefner using equation (3) for the entire period 1951-58, but although wind speed and vapor pressure data were recorded at the airport, no record of water-surface temperature was obtained at Lake Hefner. Available monthly water-budget evaporation data are shown in Table 3.

Table 3.--Monthly evaporation from Lake Hefner (in inches).

Month	1950	1951	1958
Jan.		2.466	
Feb.		-0.638	
Mar.		3.390	
Apr.		2.730	
May	3.740	3.489	2.904*
June	6.351	5.872	7.678
July	6.498	7.177	7.741
Aug.	7.390	8.828	7.627
Sept.	5.643		6.532
Oct.	6.513		5.753
Nov.	5.989		
Dec.	2.842		
June-Aug.	20.239	21.877	23.046

*May 18-31

For the 3 years 1950, 1951, and 1958, data are available for June, July, and August of each year. The total for the 3-month period was slightly higher in 1958 than in 1950 and 1951. The 1951 and 1958 results are believed to be reasonably representative of average summer evaporation, for wind speeds were approximately normal. Percent of possible sunshine and wind speeds in July and August 1950 were below normal, however, and rainfall was above normal, indicating that evaporation that summer was probably less than average.

Reduction in Evaporation

Using the method of analysis previously described, the reduction in evaporation due to application of the hexadecanol film during the period July 7 to October 2, 1958 was computed to be 9 percent, and the resulting rise in water surface temperature was 1° C. The observed evaporation during the entire period was 4,503 acre-feet; without the film the evaporation would have been 4,953 acre-feet, a saving of 450 acre-feet. The reduction in evaporation was also computed for certain shorter periods designated by the Bureau of Reclamation. The results are as follows:

Table 4.--Reduction in evaporation and rise in water surface temperature for selected periods at Lake Hefner, Oklahoma.

Period	Evaporation		Reduction in evaporation		Rise in water-surface temperatures (°C)
	Observed (acre-ft)	Natural (acre-ft)	(acre-ft)	(percent)	
1958					
July 15-25	596	665	69	10	1.3
July 27-Aug. 7	648	733	85	12	1.3
July 31-Aug. 7	426	464	38	8	1.2
Aug. 10-16	323	369	46	12	1.5
Aug. 10-19	478	532	54	10	1.3
Aug. 23-31	504	544	40	7	0.9
Sept. 5-12	269	311	42	14	1.2

Observations continued throughout October, but no reduction in evaporation was detected.

Conclusions

The results indicate a saving of 9 percent in evaporation during the period July 7 to October 2, 1958, with an accompanying rise of 1° C. in water-surface temperature. If the saving had been greater, the rise in water-surface temperature would also have been greater.

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LAKE HEFNER TESTS

TREATMENT AND FILM EVALUATION

FILM APPLICATION

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Bureau of Reclamation

FILM APPLICATION

The material chosen for the Lake Hefner tests is a commercially available high quality hexadecanol. Before its selection in 1956, this product had been tested extensively and found to be capable of producing significant evaporation savings. The Robert A. Taft Sanitary Engineering Center, U. S. Public Health Service, gave full clearance to the use of this product for the Lake Hefner tests. The choice of this material was on the basis of it being typical hexadecanol, commercially available, and one which had demonstrated its ability to reduce evaporation, and one having Public Health Service clearance. However, it was recognized that other products or other fatty alcohols might, in the future, prove equally or more effective. The material used has been designated as Fatty Alcohol No. 1. The analysis of this material is given in Table 5.

Table 5--Fatty Alcohol No. 1 Analysis

The analysis of the hexadecanol used at Carter Lake and Lake Hefner, as reported by the manufacturer, is given. The analysis is shown for four shipments and is differentiated by the destination, amount, and date of the shipment. The chain length analysis was performed by gas chromatographic methods and the percent hydrocarbon by infrared absorption analysis. The differences in the results are well within the ranges to be expected for this type of product and are not considered significant.

Date shipment	June 1958	June 1958	July 1958	Aug. 1958
Quantity	4,000 lb	20,000 lb	6,164 lb	14,000 lb
Destination	Loveland	Okla. City	Okla. City	Okla. City
ANALYSIS				
Acid No.	0.1	0.1	0.04	0.1
Sap Val.	0.2	0.1	0.1	0.2
I. V.	0.7	1.0	0.8	1.2
Titer °C.	47.1	47.5	47.3	47.4
Color Lovibond 5-1/4"	0.1Y-0.0R	0.2Y-0.0R	0.3Y-0.0R	0.1Y-0.0R
Acetyl Val.	195.0	196.9	196.1	194.3
Hydroxyl Val.	228.4	231.0	230.0	227.1
OTMP °C.	51.0	50.9	51.0	50.9
CTMP °C.	48.0	47.5	48.9	48.6
% Hydrocarbon	0.9	0.6	0.3	0.8
CHAIN LENGTHS				
C-12	0.2	0.5	0.69	0.69
C-14	4.4	4.2	4.01	4.01
C-16	90.3	92.4	92.89	92.89
C-18	4.8	2.9	2.07	2.07
C-20	0.3	--	T	T

The method chosen for applying the monolayer forming compound to Lake Hefner was one in which a dry powder was mechanically suspended in water and sprayed onto the surface of the lake. Two separate identical dispensing units were used in this operation; one unit being mounted in a 17-foot boat, and the other being mounted on a floating platform supported by four pontoons. The platform was propelled by a 25-horsepower outboard motor in normal operation, however, another 25-horsepower motor was mounted on the platform for emergency operation. The platform permitted easy access to the mixing equipment and permitted carrying larger loads, over 1,000 pounds, of the powdered materials. The boat, although affording more limited access to the equipment and smaller storage for the dry powder, proved to be very mobile and easy to handle in any wind conditions in which treatment was desirable. As much as 400 pounds of the cetyl alcohol could be carried in the boat at a time and this was adequate, as experience showed this was about one-half a day's supply for this lake. Figures 2 and 3 are pictures of the boat and platform, respectively.

The mixing and dispensing equipment consisted of two mixing units powered by a single engine through a pulley and clutch arrangement, which permitted the mixers to be run individually or simultaneously. The mixing chambers were made from 55-gallon oil drums. A second engine was used to power the intake and discharge pumps. These pumps were driven through separate centrifugal clutches which permitted the pumps to disengage when the motor was idling or being started. With this equipment, water was pumped from the lake by a self-priming positive displacement pump into the mixing chamber, where it was mixed with dry powdered alcohol introduced by hand scoops at the desired rate. Three mixing propellers quickly mixed the water and powder into a smooth uniform suspension, which then flowed into the discharge pump and was forced through a spray system onto the lake surface. It was found that, by proper adjustment of the intake and spraying rates, the entire process of mixing and spraying could be carried out in a continuous operation through the use of only one mixing chamber. A view of the mixing equipment mounted in the boat is shown in Figure 4.

The mixing and dispensing equipment was developed in Denver and built by the Denver Laboratories. Installation of the equipment in the boat was done in Denver. The installation in the barge was done at Lake Hefner.

Applications, weather and other conditions permitting, were made during the daylight hours 7 days a week. Often, crews started as early as 5 a.m. and worked as late as 6 p.m. Later in the summer, an effort was made to have the greatest film coverage coincide with the time of highest evaporation. To assist in choosing the best operational procedure, the daily evaporation distribution for an idealized day was prepared. This curve, Figure 5, was based upon the evaporation rate for 3-hour intervals for an idealized summer day computed by the Geological Survey using a mass transfer equation. The actual distribution for any one day may be quite different, depending upon the prevailing wind, temperature, and humidity. Using this curve, the application schedule was adjusted, whenever possible, so that the best film coverage occurred approximately between 8 a.m. and 8 p.m. The following table (Table 6) shows the total daily applications of alcohol to Lake Hefner with a breakdown as to amounts applied by the boat and the barge. During the summer of 1958, a total of 40,040 pounds of Fatty Alcohol No. 1 was applied to Lake Hefner.

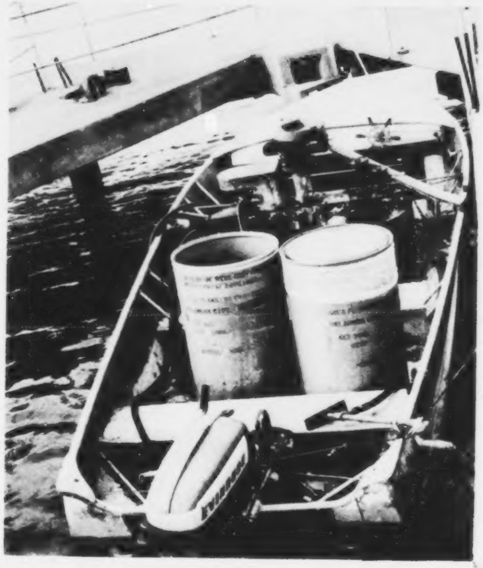

Figure 2.--Stern view of the boat used for dispensing hexadecanol at Lake Hefner. Note the two 200-pound containers in the boat.

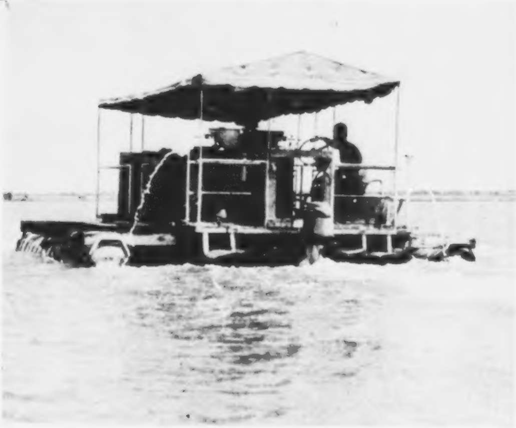

Figure 3.--Stern view of the barge used for dispensing hexadecanol at Lake Hefner. Six to eight drums of alcohol could be carried on the barge and the equipment was easily accessible for repair.

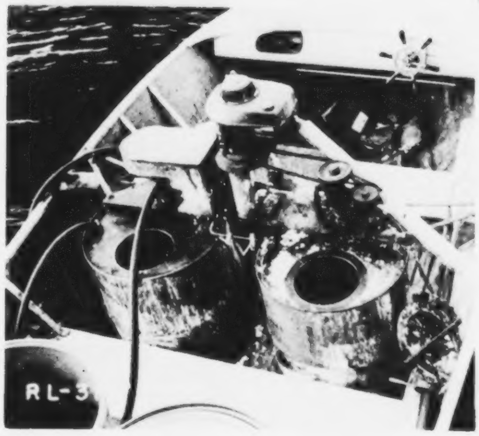

Figure 4.--Closeup of the mixing equipment in the boat. The clutch on the right mixing unit is uncovered for inspection.

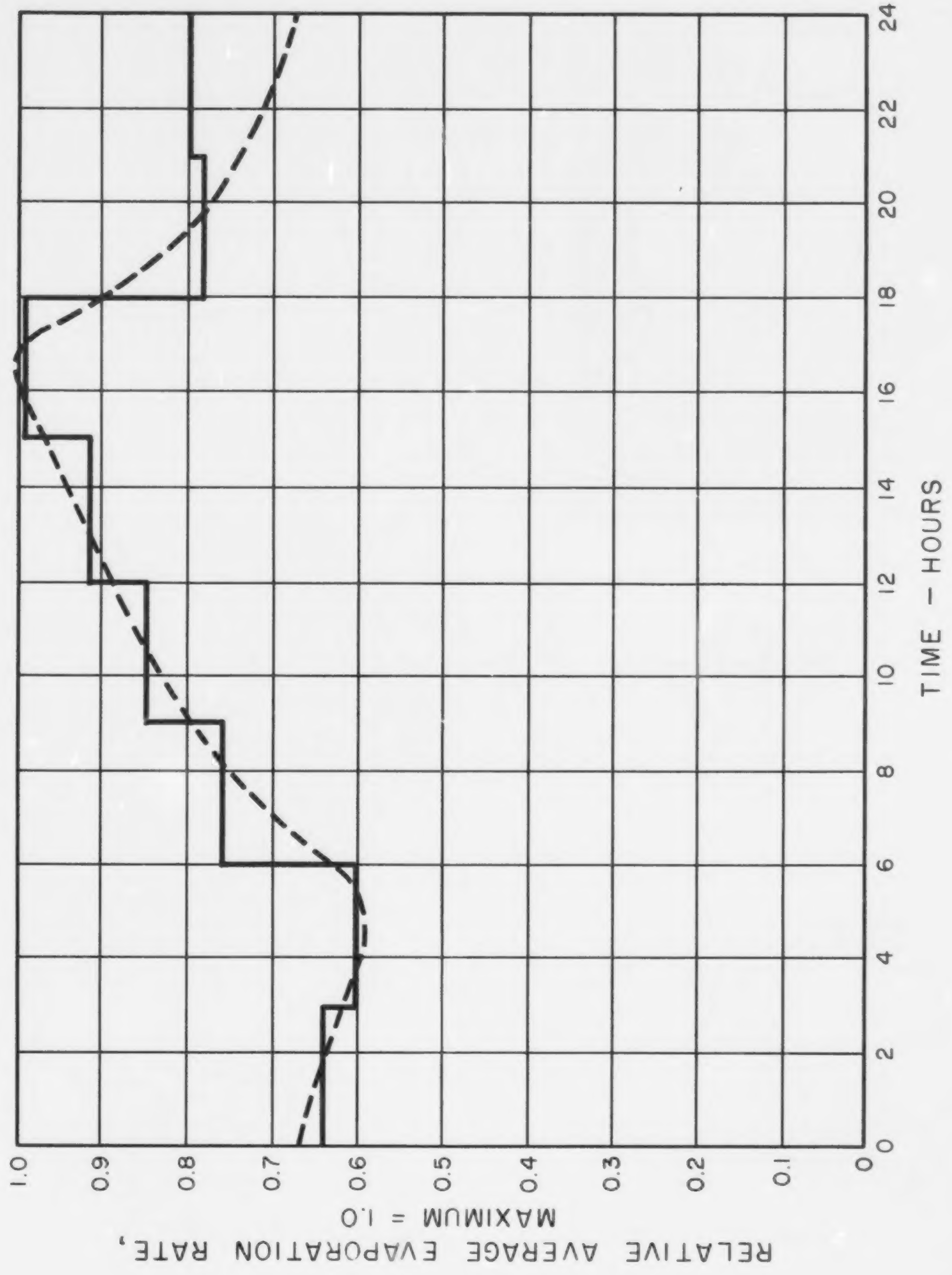

Figure 5. --Daily Evaporation Rate for an Ideal Summer Day (Lake Hefner - 1958).

Table 6.--Amount and Method of Application of Hexadecanol to Lake Hefner (1958).

Date		Equipment used and pounds applied		Total applied pounds
		Boat	Barge	
July	1	0	0	0
	2	0	0	0
	3	600	0	600
	4	0	0	0
	5	0	0	0
	6	0	0	0
	7	0	0	0
	8	350	1,050	1,400
	9	600	875	1,475
	10	400	700	1,100
	11	*	*	75
	12	750	0	750
	13	*	*	150
	14	0	0	0
	15	*	*	1,000
	16	*	*	1,000
	17	*	*	200
	18	*	*	1,000
	19	0	0	0
	20	875	0	875
	21	500	0	500
	22	*	*	700
	23	*	*	700
	24	0	0	0
	25	*	*	400
	26	300	0	300
	27	*	*	10
	28	650	175	825
	29	400	0	400
	30	50	0	50
	31	500	0	500
August	1	0	350	350
	2	275	125	400
	3	*	*	700
	4	*	*	1,025
	5	500	500	1,000
	6	575	575	1,150
	7	*	*	875
	8	0	0	0
	9	0	0	0
	10	*	*	1,100
	11	*	*	900
	12	700	0	700
	13	500	0	500
	14	450	450	900
	15	675	0	675
	16	*	*	800
August	17	0	0	0
	18	530	0	530
	19	400	150	550
	20	*	*	75
	21	0	0	0
	22	0	375	375
	23	*	*	300
	24	*	*	600
	25	*	*	675
	26	*	*	500
	27	400	450	850
	28	*	*	950
	29	*	*	275
	30	75	0	75
	31	*	*	825
September	1	125	0	125
	2	150	0	150
	3	0	0	0
	4	0	0	0
	5	450	450	900
	6	450	450	900
	7	500	500	1,000
	8	800	475	1,275
	9	*	*	500
	10	0	0	0
	11	0	0	0
	12	300	0	300
	13	0	0	0
	14	0	0	0
	15	0	0	0
	16	0	0	0
	17	0	0	0
	18	700	500	1,200
	19	0	0	0
	20	200	0	200
	21	0	0	0
	22	0	0	0
	23	0	0	0
	24	0	0	0
	25	0	0	0
	26	0	0	0
	27	0	0	0
	28	750	75	825
	29	0	0	0
	30	0	0	0
October	1	600	400	1,000
Total				40,040

*Individual barge and boat applications not recorded.

LAKE HEFNER TESTS

TREATMENT AND FILM EVALUATION

FILM EVALUATION AND COVERAGE DETERMINATIONS

By Q. L. Florey, R. Foster,
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U. S. Department of the Interior
Bureau of Reclamation

FILM EVALUATION AND COVERAGE DETERMINATIONS

Tests conducted on the smaller lakes and reservoirs prior to the Lake Hefner tests had indicated that a method for detecting a monolayer and determining the degree of its compression would be required in evaluating the effectiveness of the monolayer as an evaporation retardant. The indicator oils described in Appendix II-A, were developed for this purpose. However, the preliminary tests at Rattlesnake Reservoir, Ralston Creek Reservoir, and Carter Lake had shown that the location of a monolayer on a large water surface could be observed visually and could be photographed easily from vantage points above the water surface.

Also, it was found that when any wind at all was blowing the monolayer was moved about the lake and remained fully compressed, except for some feathering out and decompression in a narrow transition zone along the upwind edge of the film. This transition zone was usually only a few feet wide, and the surface area involved was insignificant when compared to the total area covered by a fully compressed monolayer. For these reasons, use of the indicator oils was not generally required.

During periods of calm wind conditions, which were the exception at Lake Hefner, it was found desirable to use the indicator oils to verify suspected locations of the monolayer since, under these conditions, the entire lake surface took on the glassy appearance usually characteristic only of the areas covered by the monolayer. Even under these conditions, experience in observing the water surface permitted one to detect most areas which were covered by a monolayer. This required close observation, generally from a boat moving slowly over the lake. Photographs were of little or no value when taken during calm periods.

Determination of the extent of coverage of the monolayer was actually accomplished by several methods. Observations and photographs made from some vantage point several feet above the water surface provided the most accurate means for determining this coverage; however, the terrain at Lake Hefner provided only a few such vantage points. The method of observation most commonly employed, and one that provided quite reliable information, was that of simply driving around the lake periodically and observing the location of the film by sighting landmarks on the opposite shore. The roadbed was at least several feet above the water surface around most of the lake, and provided adequate elevation for mapping the film coverage.

Some observations were made from the Lake Hefner Filter Plant water tower, which provided a vantage point nearly 100 feet above the water surface. Several photographs, such as Figure 6, were taken from this tower to aid in mapping the film location.

Aerial photographs often were coupled with observations from the shore to provide very accurate coverage values. A few pictures, such as Figure 7, were taken from directly over the lake at about 13,000-foot altitude. Others, such as Figure 8, were taken at an angle and from 1,000 to 6,000 feet above the lake. The aerial photography was performed by the Tinker Air Force Base, U. S. Air Force, Oklahoma City. Comparison of these photographs with maps of coverage sketched from shoreline observations showed that observations from surface facilities were sufficiently accurate and, in that respect, quite adequate for our use.

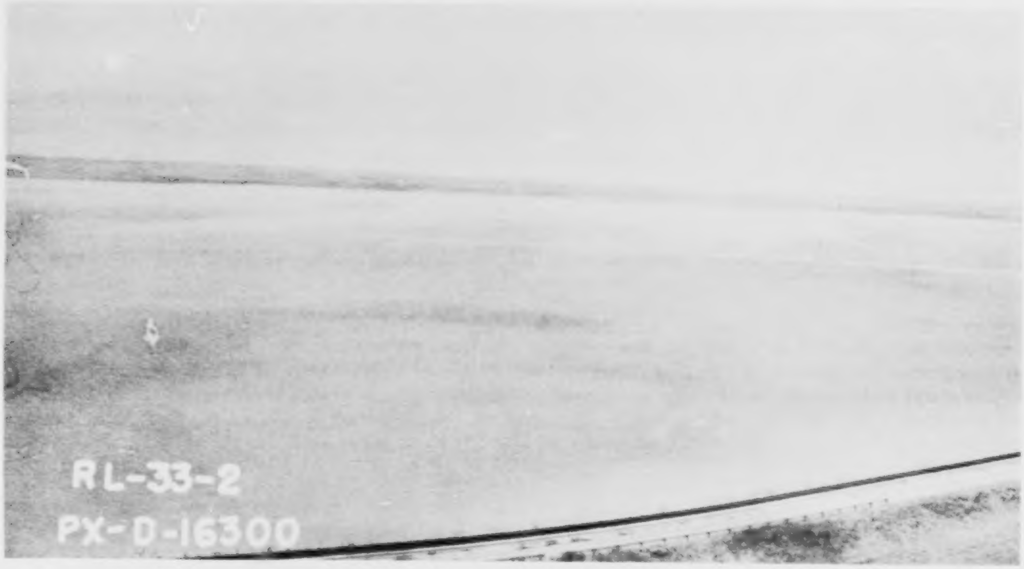


Figure 6. --Photograph taken from the water tower just east of the filter plant. The portion of the lake covered by a monolayer appears lighter in this photograph.

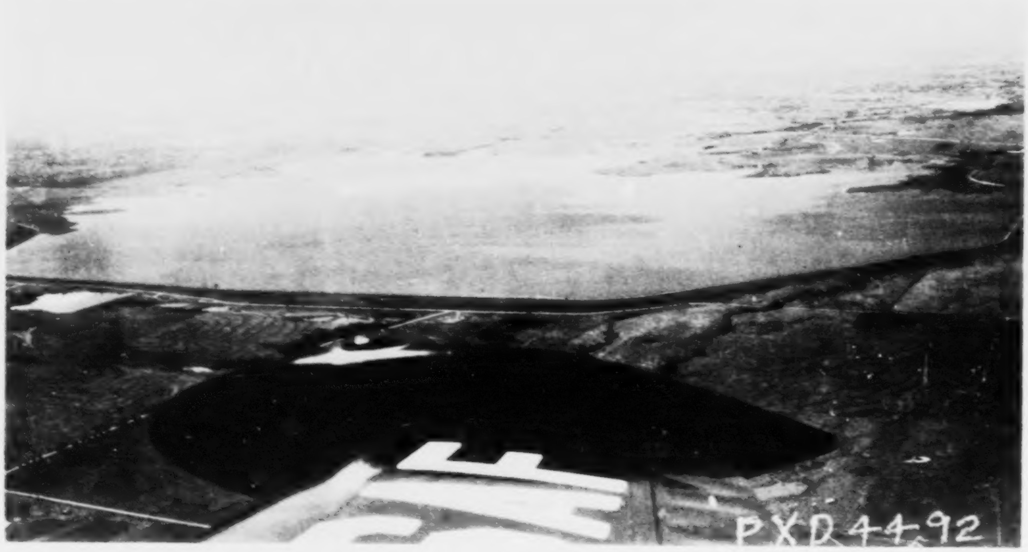


Figure 8. --Aerial photograph of Lake Hefner taken at an angle and from an altitude of 4,000 feet above the lake. The portion of the lake covered by a monolayer appears lighter in this photograph.

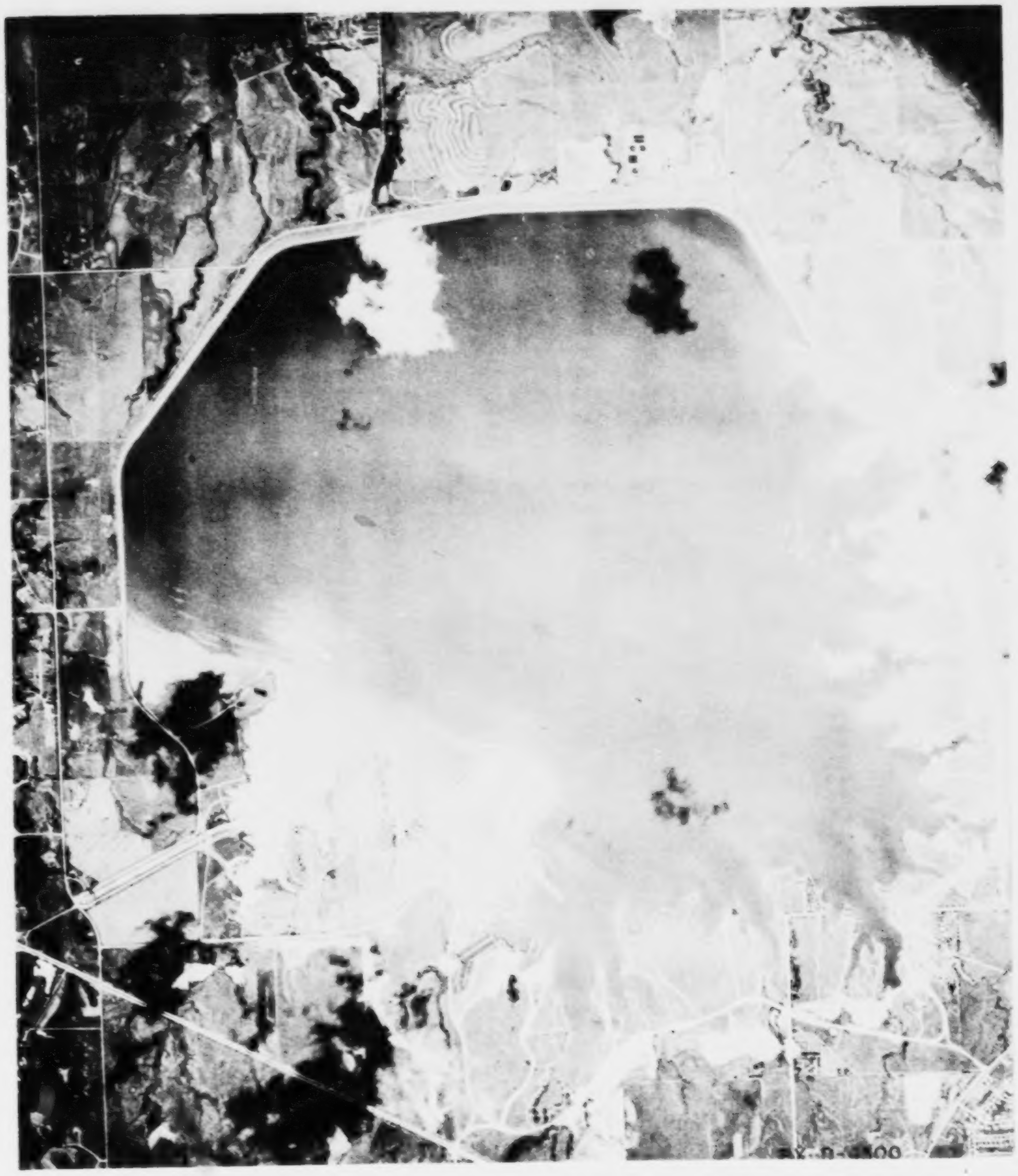
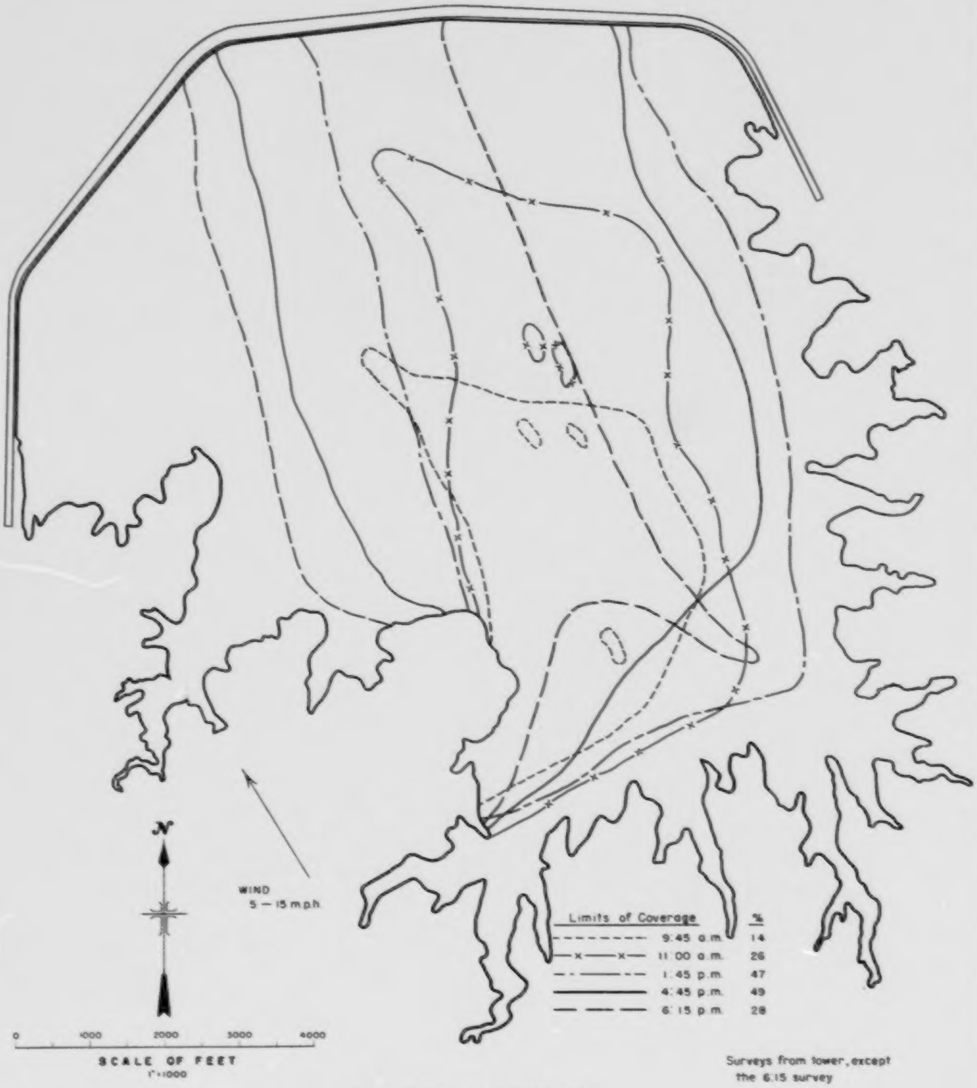


Figure 7. --Aerial photograph of Lake Hefner taken at an altitude of 13,000 feet by the Photographic Section of the Tinker Air Force Base.

The data used in estimating the evaporation savings were assembled from several sources. Mapping of the daily coverage of the water surface by the monolayer was done by Bureau of Reclamation personnel by visual and photographic methods, or use of indicator oils as described above. Location and extent of the monolayer was sketched on blank maps of the lake as frequently as time and weather conditions permitted. A typical map is shown in Figure 9. Usually, from two to five mappings per day were made Other pertinent data, such as wind velocities, were recorded either on the maps or on separate data sheets to aid in estimating fadeout times for use in determining coverage factors. Most of the photographs taken by Bureau personnel for use in mapping were taken from the filter plant water tower. The few aerial photographs taken by the Air Force were very helpful in ascertaining the accuracy of mapping by visual observation.

Data used in water budget computations were collected by the Geological Survey for use in their part of this cooperative undertaking. From these data, records of water surface temperatures were supplied to the Bureau of Reclamation for use in computing the estimated evaporation savings. These water surface temperatures were recorded at the filter plant intake tower every 6 hours throughout the test period. All other data required in these computations were obtained from Weather Bureau climatological records from the first order station at the Oklahoma City airport, which give hourly observations of the dewpoint and wind speeds required in this computation. All other observations of unique and localized meteorological conditions that could be of significance in the final analyses were noted and recorded by field personnel primarily concerned with the mapping and application of the film. These observations were particularly helpful in drawing the coverage charts, and in estimating the fadeout rates from which coverage factors were obtained.



N
WIND
5 — 15 m.p.h.
Limits of Coverage — %
9:45 a.m. 14
11:00 a.m. 26
1:45 p.m. 47
4:45 p.m. 49
6:15 p.m. 28
0
1000
2000
3000
4000
SCALE OF FEET
1" = 1000
Surveys from tower, except the 6:15 survey

LAKE HEFNER

Date 9-5-58 Res. Elev.
Crew Foster, Townsend, Northup, Mullins, Herb
Material 900 lbs. Fatty Alcohol No. 1 (SI-A-1)

Remarks Winds fairly calm, fairly good coverage all day. Extremely calm late afternoon, blow-off very slow. Both units used part of time. Dispensing stopped at 3:30 p.m.

FIGURE

Figure 9. --Typical coverage map of Lake Hefner.

LAKE HEFNER TESTS

TREATMENT AND FILM EVALUATION

DISCUSSION AND ANALYSIS OF FIELD OBSERVATIONS

By L. O. Timblin, Jr. and
Q. L. Florey

U. S. Department of the Interior
Bureau of Reclamation

DISCUSSION AND ANALYSIS OF FIELD OBSERVATIONS

For the 86 days of the application phase of the tests, treatments were made for 55 days. Applications were not made for the remaining 31 days because of several reasons which made the application either impossible or unfeasible. Listed without regard to relative importance, some of these reasons are: high winds, rain, high humidity, and maintenance and repair of equipment and scientific apparatus in operation at Lake Hefner for the tests.

The mean and maximum percent coverage for each day that a visible film was present are given in Table 7. Also given are the hours of coverage for each day. This table is the result of visual observations and in selected occasions checked by aerial photographs provided by the U. S. Air Force. In all cases, the coverage reported is for a visible film. Since even a slight breeze will fully compress the monolayer, the visible film was probably at maximum film pressure.

The maximum coverage attained at any one time was 89 percent. Coverages exceeding 90 percent were not expected because of the many small shallow coves and bays along the south and east shorelines. The prevailing winds during the summer months are from the south and east so that the film would seldom drift into these coves, and their treatment from boats is impossible because of the shallow water. The water surface area in these coves constitutes about 10 percent of the total area of the lake. With shoreline dispensers and additional staff, these areas could have been covered.

The maximum average coverage for any one day was 62 percent. For the 55 days of treatment, the average daily coverage was 16 percent and for the entire 86 days of the application phase, the average daily coverage was 10 percent.

The daily average film coverage was used as a basis for establishing the periods of computation of the estimated evaporation savings. This computation is discussed in the next section.

As observed in previous tests, the wind had a pronounced effect on the film. Even slight breezes of just a few knots would fully compress the film. Winds of up to 10 knots (about 11 mph) were helpful in establishing the monolayer on the lake surface. However, as the speed increased, it became more and more difficult with the equipment and technique used to maintain the film. The relationship between the average lake coverage and average wind speed is shown in Figure 10.

Although the correlation between wind speed and coverage is not strong (n = 57, correlation coefficient is 0.56, and the standard deviation is 12), a definite trend is indicated. Undoubtedly, the wide spread of points is the result of different operational procedures used during different days of the experiment, some of which were more effective than others. According to the correlation equation, the X axis, or wind speed, intercept is 19 knots. This indicates that at a wind speed of about 19 knots, the coverage on the average is zero. This value compares very well with the field observation that applications were impossible and impractical at speeds over about 20 mph.

Several factors affect the rate at which the hexadecanol was applied to the reservoir. Most important are: previous film coverage, wind, and the operational procedure used. Because of the unprecedented and experimental nature of the tests, new techniques of application were constantly being tried out; some were more efficient than others.

Table 7.--Maximum and Mean Coverages of a Fully Compressed Monomolecular Layer--Lake Hefner, Oklahoma City, Oklahoma, 1958.

Date	Hours of coverage	Mean coverage for period, percent	Maximum coverage (percent)
July 3, 1958	2:00 p.m.-10:30 p.m.	7	16
July 8	9:30 a.m.- 1:00 a.m.	47	89
July 9	1:00 a.m.- 5:00 p.m.	18	62
July 10	8:30 a.m.- 4:00 p.m.	24	41
July 12	10:00 a.m.- 3:00 p.m.	10	21
July 15	9:00 a.m.- 9:00 p.m.	39	61
July 16	10:00 a.m.- 8:00 p.m.	25	38
July 17-A	10:30 a.m.- 3:00 p.m.	4	5
July 17-B	4:30 p.m.- 8:00 p.m.	10	12
July 18	10:00 a.m.- 5:00 p.m.	20	27
July 20	7:00 a.m.- 1:00 a.m.	47	61
July 21	1:00 a.m.- 1:00 a.m.	17	39
July 22	1:00 a.m.-10:00 p.m.	32	75
July 23	6:30 a.m.-11:00 p.m.	41	51
July 25	1:30 p.m.-10:00 p.m.	62	86
July 26	8:00 a.m.-11:30 a.m.	8	11
July 28	6:00 a.m.-10:00 p.m.	47	66
July 29	6:00 a.m.-12:30 p.m.	12	20
July 31	2:00 p.m.- 1:00 a.m.	38	55
August 1	1:00 a.m.- 1:00 a.m.	24	47
August 2	1:00 a.m.-11:30 p.m.	38	54
August 3	6:30 a.m.-11:00 p.m.	36	50
August 4	11:00 a.m.-10:00 p.m.	45	66
August 5	5:00 a.m.- 7:00 p.m.	31	47
August 6	5:00 a.m.- 7:00 p.m.	19	33
August 7	5:00 a.m.- 5:00 p.m.	53	79
August 10	5:00 a.m.- 6:00 p.m.	29	41
August 11	5:00 a.m.- 4:00 p.m.	24	41
August 12	5:00 a.m.- 8:00 p.m.	39	50
August 13	5:00 a.m.- 4:00 p.m.	24	37
August 14	5:00 a.m.- 7:00 p.m.	46	72
August 15	5:00 a.m.- 7:00 p.m.	31	50
August 16	5:00 a.m.- 7:00 p.m.	38	69
August 18	5:00 a.m.- 6:00 p.m.	18	52
August 19	5:00 a.m.- 8:00 p.m.	38	66
August 22	7:00 a.m.- 5:30 p.m.	12	31
August 23	6:00 a.m.- 7:00 p.m.	48	72
August 24	6:00 a.m.- 4:00 p.m.	10	30
August 25	5:00 a.m.- 1:00 p.m.	14	20
August 26	6:30 a.m.- 8:00 p.m.	56	81
August 27	6:30 a.m.- 7:00 p.m.	19	44
August 28	6:00 a.m.- 6:30 p.m.	31	70
August 29	6:00 a.m.-10:30 a.m.	7	9
August 30	7:00 a.m.- 9:00 a.m.	2	3
August 31	6:00 a.m.- 7:00 p.m.	35	75
September 1	6:00 a.m.-10:00 a.m.	8	11
September 2	6:00 a.m.- 8:30 a.m.	4	5
September 5	6:00 a.m.- 7:30 p.m.	28	50
September 6	6:00 a.m.- 6:00 p.m.	44	80
September 7	6:00 a.m.- 1:00 a.m.	25	54
September 8	1:00 a.m.- 6:30 p.m.	40	80
September 9	9:00 a.m.- 4:00 p.m.	12	19
September 12	10:00 a.m.- 7:30 p.m.	26	36
September 18	7:00 a.m.- 8:00 p.m.	27	57
September 20	6:00 a.m.- 2:00 p.m.	11	16
September 28	9:00 a.m.-12:00 Mid.	14	30
October 1	9:00 a.m.- 9:00 p.m.	32	66

January 15, 1959

With so many factors influencing the application rate, it has been found that a correlation does not exist between application rate and wind speed. However, with a method refined to an operational status, such a correlation would be expected to be very good.

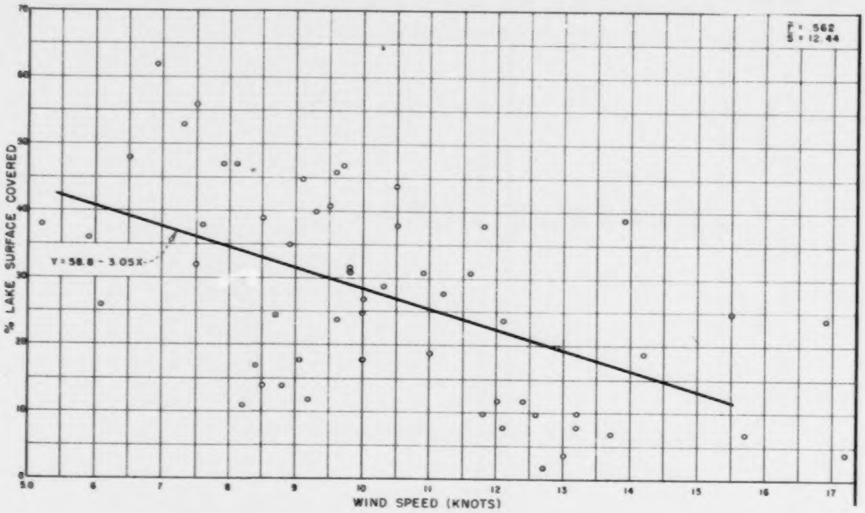


Figure 10. --Mean Coverage vs. Mean Wind Speed (Lake Hefner - 1958).

In spite of the many factors influencing the application rate, the overall picture gives a fair indication of the daily requirements. For individual days, the rate varied from about 0.1 pound per acre per day to nearly 0.5 pound per acre per day.

The applications of hexadecanol for the computation periods are summarized in Table 8. From this table, it can be seen that the rate of application was usually about 0.3 pound per acre per day.

Persistence of an established film is important to the use of monomolecular layers for evaporation reduction. Several factors cause an established film to diminish. Direct transport to the lee shore by the wind, suspension of the hexadecanol in the lake water, solution and evaporation of the hexadecanol, and biological consumption are some of the more important ways in which a film can be lost from the water surface.

Biological attrition is treated more fully elsewhere in this report and will be mentioned here only to the extent that several species of bacteria are believed to have consumed appreciable quantities of hexadecanol. Also, at the lake, fish were seen eating the ribbons of hexadecanol formed on the lee side of the lake by the accumulation of crumpled film.

Although the solubility and volatility of hexadecanol are extremely small, when several hundred pounds have almost every molecule exposed to air on one side and water on the other, significant quantities dissolve and evaporate. Using Mansfield's data, 18/ the combined loss for this condition is about 0.08 pound per acre per day.

The most obvious and possibly the most important single factor of film loss is direct blowoff. Without replenishment, a film can be seen moving before the wind across the lake. There are insufficient data to determine the velocity of the film with a given wind. However, field observations indicate that the film speed is frequently of the order of a few miles an hour.

When the film becomes decompressed, it loses its ability to reduce evaporation. A film on a reservoir surface can be decompressed in three ways: (1) The compressing force, usually the wind, goes to zero; (2) the area of the lake surface increases from wave action; and (3) some of the molecules may leave the layer by evaporation, solution, biological attrition, or suspension in the water. The film pressure-area per molecule

Table 8.--Summary--Hexadecanol Applications--Lake Hefner Tests, 1958.

Grouping designation	Period	Total pounds applied	No. of days in period	+Av lb/a/day for test period	*No. of days treated	+Av lb/a/day for days treated	USBR estimated % evap savings
Continuous periods	7/ 8-7/16	6,875	9	0.31	7	0.39	3.4
	7/17-7/27	4,675	11	.17	8	.23	4.5
	7/28-8/ 6	6,350	10	.25	9	.28	6.3
	8/ 7-8/17	6,450	11	.23	8	.32	4.8
	8/18-8/27	4,380	10	.18	8	.22	4.2
	8/28-9/ 7	5,125	11	.19	8	.26	3.2
	9/ 8-9/17	2,075	10	.08	3	.28	1.6
	9/18-9/29	2,225	12	.07	3	.30	0.9
Overall	7/ 8-10/1	39,155	86	.18	55	.28	3.6
Computation periods	7/15-7/25	6,375	11	.23	9	.28	5.5
	7/27-8/ 7	7,225	12	.24	10	.29	6.0
	7/31-8/ 7	6,000	8	.30	8	.30	7.5
	8/10-8/16	5,575	7	.32	7	.32	6.3
	8/10-8/19	6,655	10	.27	9	.30	5.6
	8/23-8/31	4,975	9	.22	8	.25	4.5
	9/ 5-9/12	4,875	8	.24	6	.33	4.8

*Applications of less than 100 pounds are not considered a treatment.
+2,500-acre area assumed for the water surface.

curve for hexadecanol, by Rosano and LaMer, 19/ indicates that about a 7 percent increase in area per molecule will reduce the film pressure to less than 10 dynes/cm. This would result in reducing the effectiveness of the film by nearly 80 percent. In winds where the waves just begin to whitecap, the film may be effectively destroyed by decompression from a combination of the increase in surface caused by waves and accelerated solution and suspension in the water caused by the waves.

The effect of the factors tending to decompress and diminish the film may be partially alleviated by excess material present, which would help supply molecules for monolayer formation, and the pressure of the wind would drift existing films into open or decompressed areas. However, this drifting action continually increases the size of the uncovered area on the upwind side of the lake.

An important factor influencing the persistence of the film at high wind velocities is the accelerated solution and suspension of the hexadecanol. The mixing action of these waves, whose amplitude may exceed 1 foot, is at least to a depth of 1 foot and, perhaps, even deeper. With this volume of water suddenly available for solution and suspension of hexadecanol when whitecapping begins, it is felt that significant amounts may be lost into the water and decompression of the film is very likely to occur. For example, at Lake Hefner about 8-1/2 pounds of hexadecanol can be dissolved in the top 6 feet of water. This would produce about a 1.7 percent increase in the area per molecule. This is nearly one-fourth the expansion of the film which reduces the evaporation reducing ability to a negligible value.

A combination of all these factors is probably responsible for the dispersion of the film at Lake Hefner, which was often observed to take place within minutes after whitecapping occurred.

REFERENCES

18. Mansfield, W. W., "The use of hexadecanol for reservoir evaporation control," paper presented at First International Conference on Reservoir Evaporation Control, Southwest Research Institute, San Antonio, Texas, April 14, 1956.

19. Rosano, H. L., and LaMer, V. K., "Rate of evaporation of water through monolayers of esters, acids, and alcohols." Journal of Physical Chemistry, vol. 60, pp. 348-353, 1956

LAKE HEFNER TESTS

TREATMENT AND FILM EVALUATION

COMPUTATION OF EVAPORATION SAVINGS

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U. S. Department of the Interior
Bureau of Reclamation

COMPUTATION OF EVAPORATION SAVINGS

Careful film surveys were taken to record the film coverage each day of the test; also, records were kept concerning other important aspects of film application, such as the hours of treatment and amount applied. This information was secured to provide a basis for interpreting the data as determined by the Geological Survey on the actual accomplishment of reservoir evaporation loss reduction. Although the Geological Survey's figures would state how much evaporation was saved, that result by itself would not serve to evaluate the performance of the film. For example, should the results have turned out to be negligible, it would not be known whether such a result might have been due to the ineffectiveness of a film under practical conditions to reduce evaporation losses or whether the lake coverage was so inadequate and the film of such an inefficient character that no practically significant evaporation reduction was effected by the surface treatment.

The effectiveness of coverage of the lake, as indicated by both the fractions of the area covered and the efficiency of the film for the prevailing temperature together with the distribution of evaporation potentialities had to be considered in our endeavor to interpret the meaning of the Geological Survey's findings. The evaporation potentialities were especially important; since, if one were to assume a complete coverage of the reservoir with a fully compressed monolayer having the maximum effectiveness in evaporation reduction, there would still have been no savings had the meteorological conditions been such that no evaporation loss would have occurred. Thus, under this hypothetical condition, the film would have had no opportunity to exert any effectiveness. Also, all of the conditions which would cause the field test to yield zero evaporation savings would result in the estimated savings being zero.

Another reason for the computations of evaporation savings based upon reservoir surface and meteorological conditions was to ascertain whether or not it would be possible to arrive at an estimate of evaporation reducing effectiveness of a surface treatment without the necessity of water and energy budget measurements of a lake. The results of two Bureau of Reclamation independent determinations are shown in Table 9. Initially a simple but probably less precise procedure, referred to as Method No. 1, was followed, while at the same time the more laborious but potentially more accurate Method No. 2 was being performed.

In making these computations from meteorologic and coverage data by Method No. 2, the four factors defined below were used:

c = Coverage factor or fraction of the lake covered with a fully compressed monolayer

f = Temperature-evaporation reduction factor

u = Wind speed in knots

$(e_o - e_h)$ = Difference in vapor pressures for saturated air at the water surface temperature and for the air temperature at some height h, millibars (in these computations h is taken as 6 feet)

This computation procedure is based on the established concept that the distribution of natural evaporation during the computation period would be proportional to the product $P = u\,(e_o - e_6)$. Since the result of this computation is expressed as percentage effectiveness, the actual amount of the natural evaporation need not be known. In Method No. 2, the products, P, were computed for 3-hour intervals by using average u and e_6 from meteorological observations made at the U. S. Weather Bureau station at the Oklahoma City airport and e_o based on water surface temperatures recorded at Lake Hefner. The U. S. Bureau of Reclamation computations did not use data upon which the Geological Survey based its mass transfer and energy budget computations, with the one exception of water surface temperature. No attempt was made to correct the water surface temperature of Lake Hefner for any possible temperature rise due to reduction of evaporation, since such data were, by prior arrangement with the Geological Survey, not made available to the Bureau of Reclamation for these computations.

The evaporation savings computed for any 3-hour interval is taken to be the product of the three factors, c, f, and **F** where c and f are as defined above and **F** represents the evaporation distribution during the computation interval. The factor **F** was obtained by summing the average values of the product $P = u\,(e_o - e_6)$ for each day of the test period and using the reciprocal of this sum as a multiplying factor, F^1, which is related to **F** and P_{av} by the equation

$$F = F^1 P_{av}$$

The factor c was obtained by plotting a curve of surface coverage versus time of day for each day of the test, and then reading the average value of coverage for the computation increment desired. Figure 11 is the film coverage versus time curve that was used to obtain the c factors shown for September 5 in Column III of the sample calculation, Table 10. This curve was plotted from information shown on the coverage map, Figure 9, which was filled in by observers at the lake during the day of September 5, as the applications progressed.

The temperature-evaporation reduction factors given in Column V of Table 10, which were found to be a function of the water surface temperature, were read from Figure II-C-3 of Appendix II-C, water surface temperature-evaporation reduction factor correlation curve for the average water surface temperature prevailing during the test increment. The tests to establish this correlation were conducted in class A evaporation pans at the Reclamation Laboratories in Denver during the period from May to October 1958, while the Lake Hefner investigation was in progress. Since the film seldom persisted for more than 24 hours at Lake Hefner, these temperature-evaporation reduction correlation data were taken for the first 24 hours of each test in plotting Figure II-C-3. These data apply only to the material designated as Fatty Alcohol No. 1, which was applied to Lake Hefner in these tests. Other fatty alcohols were tested concurrently. It was found that several of these materials were at least as good as, or better than, the Fatty Alcohol No. 1 for this application. In all cases, however, the ability of the material to inhibit evaporation dropped off with increasing ambient temperatures. These tests are discussed more fully in Appendix II-C.

The values shown in Table 9 for Method No. 1 were obtained by use of the simplifying assumption that the daily evaporation distributions were equal over the test period. Although this method is not expected to be as accurate as Method No. 2, it is simpler to carry out. The values for evaporation savings reported to the Committee of Collaborators on December 18, 1958, were obtained by Method No. 1.

The following table shows the savings for several test periods as computed by these two methods compared to the evaporation savings as observed by the Geological Survey:

Table 9

SUMMARY SHEET
ESTIMATED EVAPORATION SAVINGS
Lake Hefner Tests 1958

	USGS data			USBR data			
	Natural evap acre-feet	Savings		Method No. 1 Savings		Method No. 2 Savings	
Period		Acre-feet	Per-cent	Acre-feet	Per-cent	Acre-feet	Per-cent
1	2	3	4	5	6	7	8
July 15 through July 25	665	69	10	37	5.5	33	5.0
July 27 through August 7	733	85	12	44	6.0	38	5.2
*July 31 through August 7	464	38	8	35	7.5	32	6.9
*August 10 through August 16	369	46	12	23	6.3	24	6.4
August 10 through August 19	532	54	10	30	5.6	30	5.7
August 23 through August 31	544	40	7	25	4.5	21	3.8
September 5 through September 12	311	42	14	15	4.8	16	5.1
OVERALL RESULTS							
July 8 through October 1	4,953	450	9	180	3.6	170	3.4

*These days are also covered by longer periods.

The values of the observed and estimated savings (by Method No. 2) in acre-feet have been plotted in Figure 12. The linear relationship between these two sets of data has been computed by the least squares method. The correlation coefficient $\bar{r}$, is 0.67 and the standard deviation, $\bar{s}$, is 5.73.

A number of exploratory computations were attempted using multiple-coorelation analysis procedures, but the results obtained to date have not yielded any usable multiple-correlation equations.

The evaporation savings reported for Methods No. 1 and 2 are the results of estimating the performance of the film from meteorological and monolayer data. The actual evaporation savings, accomplished during the test, are those reported by the Geological Survey. The degree of agreement between the two is an indication of the validity of the estimating method. Although the results of our endeavors to compute evaporation reduction effectiveness of a surface treatment of a reservoir with a monomolecular layer are encouraging, much remains to be done before the estimating techniques are sufficiently refined to make them useful as a routine procedure to judge the effectiveness of practical treatments of the surfaces of operating reservoirs.

Sample Calculation

Calculations using Method No. 2 are shown in Table 10. Each day of the computation period is divided into 3-hour intervals, as shown in Columns I and II. Column

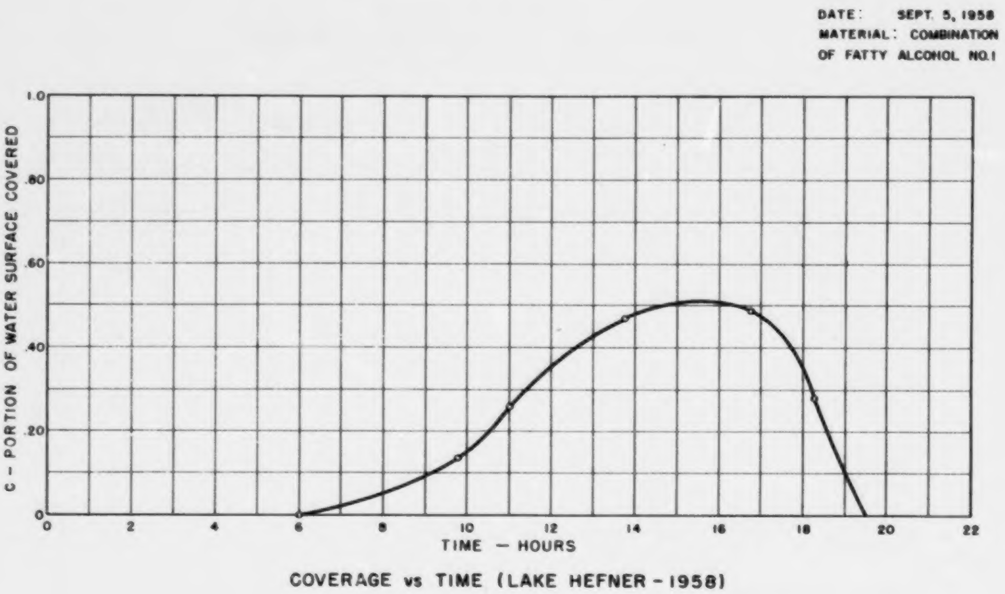

Figure 11. --Coverage vs. Time (Lake Hefner - 1958).

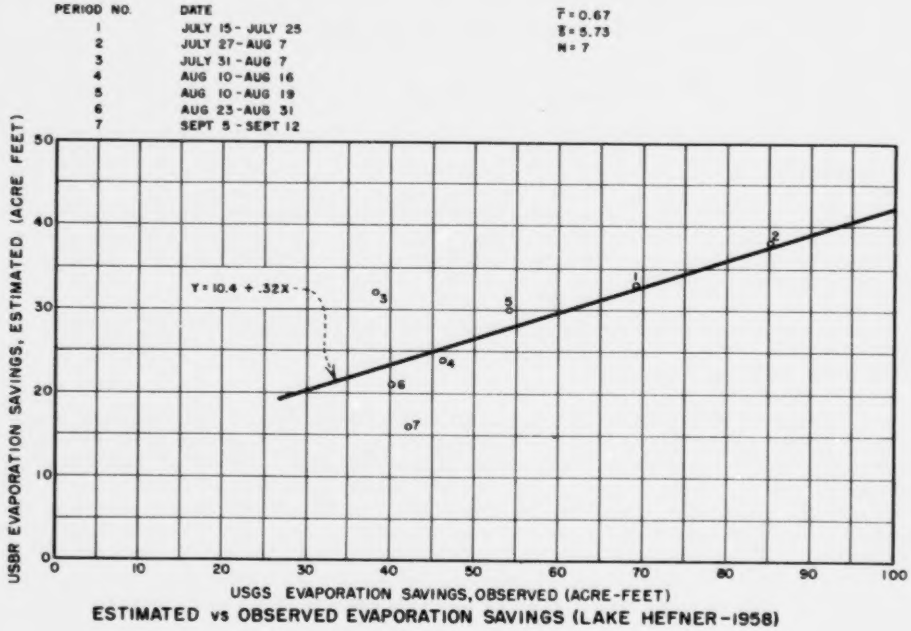

Figure 12. --Estimated vs. Observed Evaporation Savings (Lake Hefner - 1958).

Table 10.--Sample Computation--Evaporation Reduction--Lake Hefner Tests.

(I) Date	(II) Time	(III) (c) Portion of lake covered	(IV) Water surface temp in °C	(V) (f) Evap red. factor	(VI) (f)(c)	(VII) u Wind speed (knots)	(VIII) Dewpoint °F	(IX) Dewpoint °C	(X) e_0 Millibars	(XI) e_6 Millibars	(XII) (e_0-e_6)	(XIII) P = $u(e_0-e_6)$	(XIV) P by days	(XV) P (av) by days	(XVI) F Evap dist. factor	(XVII) Ffc
9/5	0-3		26.0			9.5	66.2	19.0	33.6	22.0	11.6	110.2			0.123	
	3-6		26.0			8.5	66.5	19.2	33.6	22.2	11.4	96.9			.123	
	6-9	0.03	26.0	0.39	0.012	11.2	68.2	20.1	33.6	23.5	10.1	113.1			.123	0.0015
	9-12	.23	26.0	.39	.090	10.8	69.2	20.7	33.6	24.4	9.2	99.4			.123	.0111
*	12-15	.45	26.0	.39	.176	10.5	68.2	20.1	33.6	23.5	10.1	106.0			.123	.0216
	15-18	.45	26.0	.39	.176	12.2	69.2	20.7	33.6	24.4	9.2	112.2			.123	.0216
	18-21	.08	26.0	.39	.031	10.8	69.8	21.0	33.6	24.9	8.7	94.0			.123	.0038
	21-24		26.0			9.0	68.3	20.0	33.6	23.4	10.2	91.8	823.6	103.0	.123	
9/6	0-3		26.0			8.5	66.8	19.3	33.6	22.4	11.2	95.2			.116	
	3-6		26.0			8.5	67.5	19.7	33.6	22.9	10.7	91.0			.116	
	6-9	.17	26.0	.39	.066	7.5	69.0	20.6	33.6	24.3	9.3	69.8			.116	.0077
	9-12	.42	26.0	.39	.164	10.5	71.5	21.9	33.6	26.3	7.3	76.6			.116	.0190
	12-15	.65	26.0	.39	.254	11.2	68.2	20.1	33.6	23.5	10.1	113.1			.116	.0295
	15-18	.55	26.0	.39	.214	13.2	66.2	19.0	33.6	22.0	11.6	153.1			.116	.0248
	18-21		26.0			9.5	67.2	19.6	33.6	22.8	10.8	102.6			.116	
	21-24		26.0			8.8	69.8	21.0	33.6	24.9	8.7	76.6	778.0	97.2	.116	
9/7	0-3		27.1			9.2	69.0	20.6	35.8	24.3	11.5	105.8			.152	
	3-6		27.1			8.2	67.8	19.9	35.8	23.2	12.6	103.3			.152	
	6-9	.07	27.1	.37	.026	7.5	67.8	19.9	35.8	23.2	12.6	94.5			.152	.0040
	9-12	.35	27.1	.37	.130	9.8	68.2	20.1	35.8	23.5	12.3	120.5			.152	.0198
	12-15	.38	27.1	.37	.141	12.2	67.5	19.7	35.8	22.9	12.9	157.4			.152	.0214
	15-18	.28	27.1	.37	.104	15.0	65.0	18.3	35.8	21.0	14.8	222.0			.152	.0158
	18-21	.26	27.1	.37	.096	9.5	66.2	19.0	35.8	22.0	13.8	131.1			.152	.0146
	21-24	.24	27.1	.37	.089	7.5	68.5	20.3	35.8	23.8	12.0	90.0	1,024.6	128.1	.152	.0135
9/8	0-3	.23	27.2	.37	.085	6.5	67.8	19.9	36.1	23.2	12.9	83.8			.153	.0130
	3-6	.24	27.2	.37	.089	5.8	67.0	19.4	36.1	22.5	13.6	78.9			.153	.0136
	6-9	.53	27.2	.37	.196	5.0	68.0	20.0	36.1	23.4	12.7	63.5			.153	.0300
	9-12	.75	27.2	.37	.278	8.2	68.2	20.1	36.1	23.5	12.6	103.3			.153	.0425
	12-15	.50	28.2	.36	.180	14.5	66.8	19.3	38.2	22.4	15.8	229.1			.153	.0275
	15-18	.13	28.2	.36	.047	15.0	67.0	19.4	38.2	22.5	15.7	235.5			.153	.0072
	18-21		27.5			11.0	69.5	20.8	36.7	24.6	12.1	133.1			.153	
	21-24		27.5			8.0	69.2	20.7	36.7	24.4	12.3	98.4	1,025.6	128.2	.153	
9/9	0-3		27.2			8.0	69.0	20.6	36.1	24.3	11.8	94.4			.146	
	3-6		27.2			8.2	69.0	20.6	36.1	24.3	11.8	96.8			.146	
	6-9		27.0			9.0	70.0	21.1	35.6	25.0	10.6	95.4			.146	
	9-12	.08	27.0	.38	.030	9.8	70.8	21.6	35.6	25.8	9.8	96.0			.146	.0044
	12-15	.17	27.2	.37	.063	13.8	69.8	21.0	36.1	24.9	11.2	154.6			.146	.0092
	15-18	.02	27.2	.37	.007	14.0	68.8	20.4	36.1	24.0	12.1	169.4			.146	.0010
	18-21		27.0			13.2	68.8	20.4	35.6	24.0	11.6	153.1			.146	
	21-24		27.0			11.2	69.5	20.8	35.6	24.6	11.0	123.2	982.9	122.9	.146	
9/10	0-3		26.8			10.8	69.5	20.8	35.2	24.6	10.6	114.5			.110	
	3-6		26.8			9.0	69.0	20.6	35.2	24.3	10.9	98.1			.110	
	6-9		26.5			11.8	69.2	20.7	34.6	24.4	10.2	120.4			.110	
	9-12		26.5			8.0	68.8	20.4	34.6	24.0	10.6	84.8			.110	
*	12-15		28.0			4.5	69.8	21.0	37.8	24.9	12.9	58.0			.110	
	15-18		28.0			9.5	69.2	20.7	37.8	24.4	13.4	127.3			.110	
	18-21		26.5			8.0	70.2	21.2	34.6	25.2	9.4	75.2			.110	
	21-24		26.5			6.8	70.8	21.6	34.6	25.8	8.8	59.8	738.1	92.3	.110	
9/11	0-3		26.2			8.2	70.0	21.1	34.0	25.0	9.0	73.8			.096	
	3-6		26.2			9.0	69.0	20.6	34.0	24.3	9.7	87.3			.096	
	6-9		25.5			9.2	68.5	20.3	32.6	23.8	8.8	81.0			.096	
	9-12		25.5			10.5	68.8	20.4	32.6	24.0	8.6	90.3			.096	
	12-15		24.8			9.0	67.0	19.4	31.3	22.5	8.8	79.2			.096	
	15-18		24.8			8.0	66.0	18.9	31.3	21.8	9.5	76.0			.096	
	18-21		26.0			6.5	67.0	19.4	33.6	22.5	11.1	72.2			.096	
	21-24		26.0			7.0	66.0	18.9	33.6	21.8	11.8	82.6	642.4	80.3	.096	
9/12	0-3		25.5			7.8	64.2	17.9	32.6	20.5	12.1	94.4			.102	
	3-6		25.5			5.0	63.5	17.5	32.6	20.0	12.6	63.0			.102	
	6-9		25.5			2.0	64.3	18.2	32.6	20.9	11.7	23.4			.102	
	9-12	.06	25.5	.39	.023	3.2	65.5	18.6	32.6	21.4	11.2	35.8			.102	.0023
	12-15	.32	27.0	.38	.122	6.5	62.8	17.1	35.6	19.5	16.1	104.6			.102	.0124
	15-18	.34	27.0	.38	.129	6.2	62.5	16.9	35.6	19.3	16.3	101.1			.102	.0132
	18-21	.10	26.5	.38	.038	8.5	63.8	17.7	34.6	20.3	14.3	121.6			.102	.0039
	21-24		25.5			9.5	63.5	17.5	34.6	20.0	14.6	138.7	682.6	85.3	.102	
														Σ =837.3		Σ =0.4099

*Computation of this interval described in text.

$$\Sigma P_{av} = 837.3$$

$$F' = \frac{1}{\Sigma P_{av}} = \frac{1}{837.3} = 0.00119$$

$$F = F'P_{av}$$

$$\Sigma Ffc = 0.4099$$

Percent reduction in evaporation $= \frac{100}{8} Ffc = \frac{100}{8}(0.4099) = 5.1$

III shows the fraction of the lake covered, c, for the particular 3-hour interval, as determined by field observations. The water surface temperature in ^{o}C., as reported by the Geological Survey, is given in Column IV. The evaporation reduction factor, f, is determined using the temperature in Column IV and Figure II-C-3. Hence, for September 5, 1958, 12-15 hours, the water surface temperature is 26.0^{o} C., with a corresponding evaporation reduction factor of 0.39. The product (f c) is given in Column VI as 0.176. From the Weather Bureau data, the wind speed at 55 feet above ground level is given in Column VII as 10.5 knots, and the dewpoint at 68.2^{o} F. in Column VIII (converted to 20.1^{o} C. in Column IX). From the water surface temperature in Column IV and standard tables, the saturated vapor pressure for air at the water surface temperature, e_o, is found to be 33.6 millibars as shown in Column X; and from the dewpoint in Column VIII, the vapor pressure for the air at a height of 6 feet, e_6, is found to be 23.5 millibars as shown in Column XI. The difference, e_o-e_6, 10.1 millibars, is given in Column XII. The evaporation factor, P, is found to be 106.0 by multiplying Column VII by Column XII ($u (e_o-e_6)$).

The sum of the evaporation factors for each 3-hour period of September 5 is 823.6, as shown in Column XIV, and the average is 103, as shown in Column XV. The sum of the daily average values in Column XV for the period September 5-12, 1958, inclusive, is 837.3. To determine the fraction of the total evaporation distribution for the 8 days that took place each day, the average evaporation factor for each day is divided by the sum of the daily averages (or multiplied by the reciprocal of the sum). This gives the daily evaporation distribution factor, F, as shown in Column XVI. For each 3-hour period, the fraction of the total evaporation is F/8. The evaporation savings for each 3 hours, weighted for the daily evaporation distribution, is obtained by the factor (F)(f)(c) /8. The product (F)(fc) is shown in Column XVII. For September 5, 12-15 hours, this is (0.123)(0.176) = 0.0216. From the sum of the figures in Column XVII, $\sum F$ (fc), the percent evaporation savings can be found by multiplying by 100/8; the factor 100 to convert to percent, and the factor (1/8) to take care of the eight 3-hour intervals per day used for the computation. In the example, the savings are found to be (100/8) (0.41) = 5.1 percent.

TREATMENT AND FILM EVALUATION

RESULTS OF THE ENGINEERING STUDIES

Discussion and Conclusions

By Walter H. Price, Walter U.
Garstka, and L. O. Timblin, Jr.

U. S. Department of the Interior
Bureau of Reclamation

RESULTS OF THE ENGINEERING STUDIES

Discussion and Conclusions

The field investigations of 1958 at Lake Hefner clearly demonstrated that is is possible to apply to a lake of this size (2,500 acres) a monomolecular layer which would cover up to 90 percent of the water surface. However, the maximum average cover attained for any one day was 62 percent. The average coverage for the 55 days when a visible film was present was 16 percent. The average coverage for the 86 days of the investigation was 10 percent, which indicates the degree of success of establishment of a visible layer under the conditions that prevailed during the summer of 1958 with the techniques used.

The overall evaporation savings of 9 percent, as determined by the U. S. Geological Survey, were for an 86-day period, during which treatments were made on only 55 days. High winds and other conditions made it unfeasible to make applications on the other 31 days. For several shorter periods within the 55 days, savings of from 10 to 14 percent were achieved.

Tests conducted in the laboratory concurrently with the Lake Hefner treatments indicated that the 64 percent evaporation reduction observed for hexadecanol in previous screening tests 20/ would apply only to low water surface temperatures and that the maximum effect which could be expected of hexadecanol at the temperatures prevailing at Lake Hefner would be in the neighborhood of 35 percent instead of 64 percent. A very important and practical finding of the Lake Hefner work was the recognition of the effect which wind has on the behavior of the monomolecular layer. Of all the factors influencing the survival and effectiveness of the monolayer, wind probably could be considered the most important. The wind at Lake Hefner was extremely gusty; therefore, it is difficult to choose a specific wind velocity above which the applications were impossible. However, it was found that under average wind velocities greater than about 20 miles per hour, the film would be quickly swept across the reservoir or destroyed by the waves as fast as the generating material could be applied. With breezes of up to 10 miles an hour, the wind was very helpful in establishing a monomolecular layer and fully compressing the film. Thus, that portion of the lake covered with the film was covered with a fully compressed layer. Under wind conditions more favorable than those which were experienced at Lake Hefner in 1958, it should be possible to apply a film for longer periods each day and over a greater portion of a lake surface with attendant greater savings of water.

The Lake Hefner experiment and the analyses of the data were so organized as to yield the maximum amount of information which might be extrapolated to other reservoirs and other field conditions. Although an exact agreement was not to be expected between the Geological Survey's and the Bureau of Reclamation's computations of savings, the close correlation between the two series of findings supports the validity of the temperature reduction factor and of the indicativeness of the mapping and film detection techniques, even at this exploratory stage in their development.

In view of the degree of agreement between the U. S. Geological Survey and U. S. Bureau of Reclamation findings, it is reasonable to expect greater effectiveness of hexadecanol at temperatures lower than those that prevailed at Oklahoma City. Conversely, less effectiveness would be expected of hexadecanol at water surface temperatures higher than those at Lake Hefner. Laboratory tests conducted during the summer of 1958 have shown that although hexadecanol is still one of the better performers tested, there are several materials which are superior to hexadecanol, especially at high lake water surface temperatures. Unfortunately, time did not permit the field testing of any of these materials at the 1958 Lake Hefner tests.

The equipment for the Lake Hefner tests was designed to apply and maintain the film on this large reservoir with reasonable efficiency and economy. It was fully recognized that this was not the ultimate in dispensing equipment. Now that it has been demonstrated that it is possible to apply and maintain an effective monomolecular layer on a water surface the size of Lake Hefner, and now that there has been established some concept of economic cost-benefit considerations, investigations aimed at solving specific problems for various classes of reservoirs can be considered.

There is need for improving and developing techniques for initial establishment of films and for replenishment of material lost by attrition. Although it has been demonstrated that it is possible to photograph a monolayer's suppression of the wave configuration of a water surface, there is need for improvement of photographic techniques, especially by airborne cameras. There is need of developing and verifying techniques of estimating the potential effectiveness of monolayer treatments for reservoirs, based upon reservoir and film characteristics and climatological data. There is need for further work on monolayer materials both more effective and less costly than those now in use. Some materials now available offer promise of much greater evaporation reducing effectiveness than the material used in these tests.

The U. S. Geological Survey evaluation showed that during the period of treatments, July 7 to October 1, 1958, it was possible to achieve an overall reduction in evaporation loss from the 2,500-acre Lake Hefner of slightly more than 9 percent, even though weather conditions were not favorable for maintaining the film. This is about one-fourth of the maximum evaporation reduction which would be expected with the material used at the prevailing water temperature had the lake been completely covered with a fully compressed monolayer during the entire test period.

It is evident, from the above summary of chemical engineering aspects of the 1958 Lake Hefner evaporation reduction investigation, that we have learned a great deal about the possibilities, problems, techniques, and methods of analysis in connection with monomolecular layers, and although the above information will be very valuable in the ultimate development of practical methods of reduction of evaporation losses from large reservoirs, there remains much work to be done before the full operational potentialities of this technique of evaporation reduction reach a stage of development where specific recommendations can be made for selected reservoirs with established limits or practically attainable effectiveness based upon firm cost-benefit ratio economic data.

REFERENCES

20. Timblin, L. O., Jr., Moran, W. T., and Garstka, W. U., "Use of Monomolecular Layers for Reservoir Evaporation Reduction." Journal, American Water Works Association, vol. 49, No. 7, pp. 841-848, July 1957.

THE EFFECTS OF HEXADECANOL ON WATER QUALITY, LAKE BIOTA, AND BACTERIAL POPULATIONS IN LAKE HEFNER

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In consultation and collaboration
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Guthrie, John W. Goodman,
and Stanley L. Sissom
and the 1958 Limnology class

North Texas State College, Denton, Texas

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THE EFFECTS OF HEXADECANOL ON WATER QUALITY, LAKE BIOTA, AND BACTERIAL POPULATIONS IN LAKE HEFNER

INTRODUCTION

In the evaporation control study of the summer of 1956 involving Kids Lake, it was observed that certain types of essential data would be desirable in judging the effects of hexadecanol on water quality. It was observed in that study, for example, that certain types of bacteria appeared to increase rapidly in the presence of hexadecanol; and it was inferred that the multiplication of these forms could be attributed to the utilization of the evaporant control. It was further noted that there was slight chemical change in the small lake and that the physical qualities of the water were not greatly modified.

The study on Lake Hefner was planned so as to provide an early study period of the lake prior to the time hexadecanol was added. The limnological and bacteriological studies of the lake, as well as bottom fauna and fisheries surveys, began on June 25. Five stations were established on Lake Hefner, fairly well distributed over the lake in order to obtain information concerning the physical, chemical, and biological conditions in both shallow and deep water. The map (Figure 13) shows the distributions of the sampling stations for the period of study. During the initial period studies of temperature and specific conductivity were made at each station from surface to bottom. Samples for the determination of pH, carbonates, bicarbonates, sulfates, chlorides, hardness, dissolved oxygen, and carbon dioxide were collected at intervals of surface, middle, and bottom, regardless of the depth of the station. Plankton samples were collected from the surface, middle, and bottom at Station No. 1 and from the surface only at the other four stations. The organisms encountered were figured in terms of areal standard units. Bottom fauna were collected from the five different stations on three occasions, the number of organisms being separated from the debris and mud by sifting the material through a No. 40 standard USGS soil sieve. The total accumulation from each station was counted and calculated in terms of organisms per square foot. Experimental gill nets, 500 feet in length, were set in different areas in the lake in order to procure an estimate of the fish population in Lake Hefner. Two 1,000-foot trammel nets were also used at the different stations in order to catch a representative sample. Bacteriological samples were collected from each of the five stations at top, middle, and bottom, and were sent to the laboratory at North Texas State College for qualitative and quantitative determinations.

The above investigations continued through the seventh day of July, the final laboratory work being completed on the ninth. During this period the surface of the lake was devoid of hexadecanol, except for the addition of 600 pounds on July 3 distributed near the boat harbor. The purpose of these preliminary investigations was to obtain information concerning the conditions in Lake Hefner so that any changes that might occur in the chemical, physical, or biological characteristics of the lake that could possibly be attributed to the addition of hexadecanol, would be apparent.

After the seventh of July, for a period of 21 days during that month, hexadecanol was added to Lake Hefner. The only days during which it was not added resulted from sufficient turbulence due to wave action so that it was impractical to attempt to use the barge. A schedule was provided for continuing the investigations on Lake Hefner at intervals of approximately every two weeks. The limnological and bacteriological data

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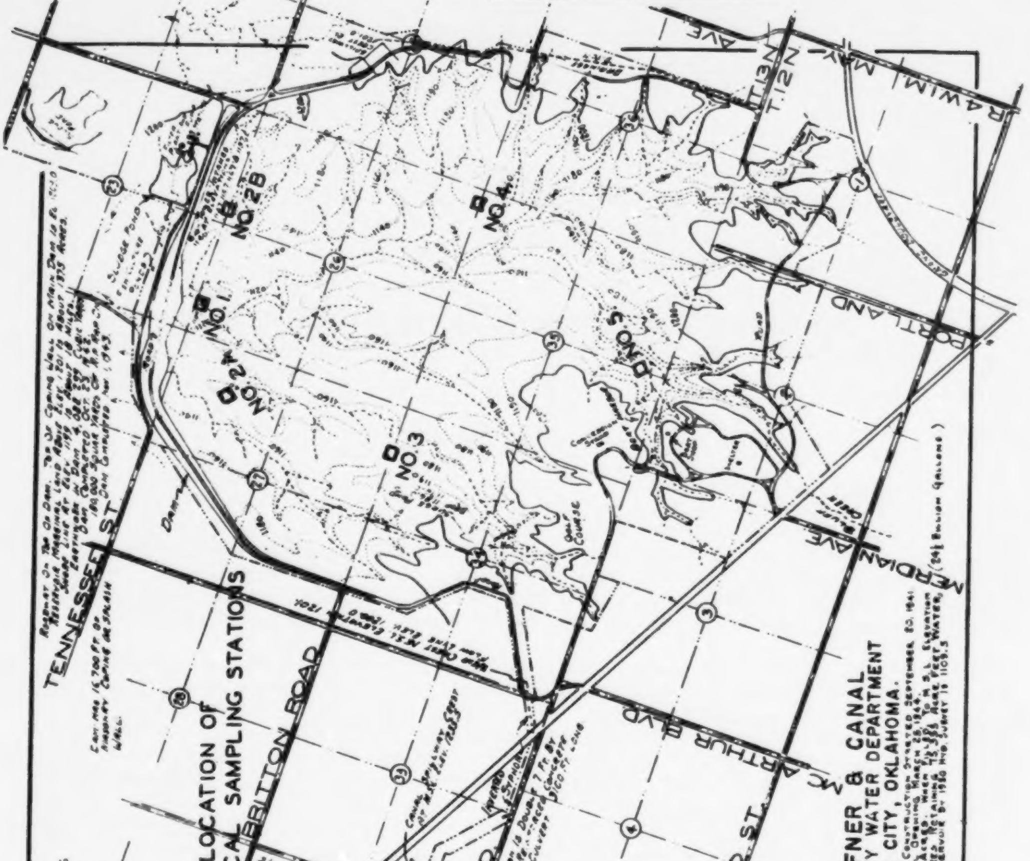
LAKE HEFNER & CANAL
OKLAHOMA CITY WATER DEPARTMENT
OKLAHOMA CITY, OKLAHOMA.
▫=LOCATION OF BIOLOGICAL SAMPLING STATIONS
NO. 1
NO. 2A
NO. 2B
NO. 3
NO. 4
NO. 5
TENNESSEE ST
BRITTON ROAD
WILSHIRE BLVD
N. 63RD ST.
N. 50TH ST.
MERIDIAN AVE
MAY AVE
PORTLAND
MC ARTHUR BLVD
WEST AVE
COUNCIL RD
CANAL
OKLAHOMA CITY MUNICIPAL AIRPORT NO. 2
LAKE OVERHOLSER
SEDIMENTATION BASIN
T.13N
T.12N
R4W
NORTH
SCALE 1"=2000 FT.
LEGEND

Figure 13

were collected on July 28, August 15, August 28, September 12, September 26, October 11, and October 31. Plankton counts were made from the five stations at weekly intervals, beginning on July 22 and continuing through the experimental period. The last addition of hexadecanol was made to Lake Hefner on October 1, and it was agreed that studies would be continued after that date in order to gain information concerning the time necessary for the effects of this material to be lost insofar as residual effects were concerned. Thus an experimental period of approximately 3 months is included in this report, beginning near the end of July and continuing through the month of October. This comprehensive survey indicates the general effects of hexadecanol on a water supply reservoir. There were, however, intermittent observations that will be included in the report that are not necessarily quantitative in nature since no means were available for getting quantitative data. This refers especially to the loss of hexadecanol around the perimeter of the lake due to wave action. Also, observations were made on the activity of certain species of fish in the consumption of the hexadecanol from the surface of the lake. This latter observation is a rather interesting and novel one since the literature has no citations that make a similar reference. Possibly the reason for the sparsity of information on this subject may be attributed to the unusual conditions in which the hexadecanol existed. It appeared that the movement of the barge sometimes was slower than the spreading effect of the hexadecanol, in which instances the chemical would form into strings and float for a while, later submerging. On quiet evenings or early mornings the surface of the lake supported numerous channel catfish, river carp, and European carp, intermittently breaking the surface film to obtain strings of the chemical for food. We are aware that this material may be consumed, as was shown by work at the Robert A. Taft Sanitary Engineering Center. We have not determined, however, what attracted the intense populations of fish to surface. Possibly the heavy layer of hexadecanol on the surface of the water might have produced peculiar lighting effects below that initiated the attraction, and once the fish began to consume the hexadecanol they seemed to be unusually enthusiastic about continuing the same procedure. When the water was rough, there was no apparent surface fish population although near the riprap one could observe large schools of mixed species of fish feeding on the strings of hexadecanol that were caught in the undertow and consequently carried down, and a slight distance away, from the retaining dam.

EARLY STUDY PERIOD

At the time the investigation began on Lake Hefner, summer stratification had already started. Station 1 was about the only area of intense investigation that had a rather stable thermocline. On June 28 the physical-chemical data from Station 1 indicated a typical condition of thermal stratification as observed in Southwestern reservoirs. The top of the thermocline was near 17 meters and the bottom appeared to be at 19 meters. The hypolimnion extended down to the bottom, which was to a depth of 26 meters. As observed in Table 11, the specific conductivity was higher above and through the thermocline than it was in the epilimnion or the hypolimnion. The dense layer was observed not only at this period, but until summer stagnation terminated. Oxygen depletion down to a low concentration occurred in the hypolimnion, while free carbon dioxide was obtainable only in that area. Actually there was little differential in the water quality on the surface and that on the bottom. Since the other stations did not show complete stratification, one may conclude that a depth of 12 meters, which was about maximum for any other station, resembled the chemical characteristics shown in Table 11. On occasions during the first two weeks there were variations in oxygen content; but the other characteristics, including temperature, did not alter greatly. These data represent the water quality conditions in Lake Hefner for the early study period.

Since our previous investigations on the effects of hexadecanol on lake biota had been very informative, we were interested in the bottom fauna studies. Table 12 indicates the results of several samplings from Station 1, and it is interesting to note that the population was extremely low. Even though several square feet were procured by different types of dredges, we were never able to demonstrate a sufficient population to warrant a continuation of this study. Therefore, bottom fauna investigations were discontinued.

Samples were collected for qualitative and quantitative determination of bacteria from the various stations, as shown in Table 13. One may observe that Pseudomonas

Table 11. --Physical and Chemical Data Record.

Station 1

Date 28 June '58

Time 0900-1300

OKLAHOMA CITY EVAPORATION CONTROL STUDY
1958
LAKE HEFNER

Physical, Chemical Data

Records by J. K. G. Silvey,
John Goodman, Stanley Sissom

Parts Per Million or Mg. Per Liter

Sky Clear

Wind 20 Kts.

Air Temp. 36.5° C.

Depth M	Temp. C°	Spec. Cond.	pH	CO_3	HCO_3	SO_4	Cl	Hard. $CaCO_3$	O_2	CO_2
1	26	600	8.8	10	178	94.5	62	192	7.4	0
2	26	600								
3	26	600								
4	26	600								
5	26	600								
6	26	600								
7	26	600								
8	26	600								
9	26	600								
10	26	650								
11	25.9	650								
12	25.5	650								
13	25.1	650								
14	25.0	650	8.4	4	182	92.5	62.8	193	7	0
15	24.8	650								
16	24.1	650								
17	23.5	650								
18	22.3	650								
19	17.9	650								
20	17.7	600								
21	17.6	600								
22	17.45	600								
23	17.25	600								
24	17.2	600								
25	17.1	600								
26	17.1	600	7.6	0	194	93.5	64.3	200	1.2	5.5

Table 12. --Bottom Fauna Record.

N. T. S. C. Biology Department

Bottom Fauna

Locality: Hefner	**Depth:** 25 Meters	**Apparatus:** Ekman and Petterson Dredges
Date: June 25-July 9	**Sample Area:** Station 1	**Recorded by:** Limnology Group
Time: Afternoon	**Sky:** Clear	
Wind: South-Variable		

Name of Organism	Average Quantity
Chaoborus	2
Chironomus	2

Total 4

Number per square feet 2

Total number per acre ____________

Table 13. --Bacteriological Data Record.

OKLAHOMA CITY EVAPORATION CONTROL STUDY
1958
LAKE HEFNER

Date Collected June 27, '58

Date Plated June 27, '58

Date Counted June 30, '58

Bacteriological Data

Records by R. K. Guthrie
(For physical and chemical data, see attached sheets)

ORGANISMS PER ML.

LOCATION	1	2	3	4	5	6	7	8	9
Sta. 1 Top	4		4						
Sta. 1 Mid.	12	6	6			32		36	
Sta. 1 Bot.	8	4		78	174	300		34	
Sta. 2 Top	36	4	12						
Sta. 2 Mid.									
Sta. 2 Bot.	60	2		16	12				
Sta. 3 Top	8		24			160		328	
Sta. 3 Mid.	16	2						48	
Sta. 3 Bot.	104		2	2000	1600				
Sta. 4 Top	74					16			
Sta. 4 Mid.	28					32		92	
Sta. 4 Bot.				TNTC	TNTC				
Sta. 5 Top	8					12		1700	
Sta. 5 Mid.	150		6			120		12	
Sta. 5 Bot.			12	TNTC*	TNTC	TNTC			

KEY:

1. **Bacillus**
2. **Fungi**
3. **Actinomycetes**
4. **Pseudomonas**
5. **Alcaligenes**
6. **Aerobacter**
7. **Escherichia**
8. **Staphylococcus**
9. **Others**

* Too numerous to count

NORTH TEXAS STATE COLLEGE, DENTON, TEXAS

and Alcaligenes, the two organisms that increased in the Kids Lake study, were not recovered from the top or middle at any station, but were obtained in the bottom samples. Since these organisms are frequently associated with soil, their presence was anticipated; and if the bottom had not been roiled when samples were collected, it is highly probable that these organisms would not have appeared in our early data. The general situation in regard to bacteria indicated a rather normal flora; and when compared with similar lakes in the area, they were found to be relatively low in total number of organisms per milliliter. There were two sets of samples taken during the early period of study so as to be certain of the general bacteriological population. Since there was little difference in the total counts, Table 13 is quite representative of the population as it existed prior to the time the hexadecanol was added.

There are no citations in the literature that indicate that hexadecanol has a direct effect on any of the plankton organisms. Since a study of these organisms is important in water supplies, our study was undertaken in order to get a general listing of the organisms and their relative abundance insofar as areal unit counts was concerned. Each station was sampled four times between June 25 and July 9, and an average count was assembled so that any increase or decrease that appeared to be unusual in the experimental period could be readily descerned (Table 14). It is proper to emphasize that Oklahoma City Water Department has been doing complete plankton counts for a number of years. Therefore, there was additional data that may be readily used as a reference to observe if the plankton counts procured during the early study period were relatively similar to previous counts taken from Lake Hefner. In reviewing the counts for the past 7 years, it would appear that the organisms present and their relative abundance, as shown in Table 14, was quite similar to those found in previous studies made during the latter part of June and the early part of July. The total plankton organisms on an average basis found in the surface samples at Station 1 was 223 areal units. The average during the past 7 years was 194, except for two sporadic blooms of unicellular chlorophyta; otherwise the composition of the plankton organisms was similar. It would thus appear that there were few, if any, unusual characteristics shown in the plankton studies for the period under consideration.

In order to obtain a complete picture of the general biota of the lake, the fish taken by nets were counted, weighed, measured, and identified. Table 15 illustrates the results of those studies. Unfortunately, it was not possible to do similar investigations at the conclusion of the experimental period although previous studies of the fish population in Lake Hefner during the past seven summers are very similar to those shown in Table 14. Since it has been shown that hexadecanol is not toxic to fish, we did not anticipate any reduction in the population. We regret, however, that studies could not be made in the latter part of September since our observations on the intensity of fish feeding on hexadecanol might have demonstrated some interesting changes either in the fish composition or in the average condition of some of the species.

EXPERIMENTAL PERIOD

1. Chemical and Physical Data

The first addition of hexadecanol sufficient to form a monolayer over most of Lake Hefner was made on the morning of July 8. During the next 3-week period a total of 12,860 pounds was added to the lake. Since it was desirable to obtain as much limnological data as possible concerning the effects of the monolayer on chemical quality, a detailed study was made at 2-week intervals. It is not necessary to include all data from this study but only those that represent specific periods during the investigation. Since over 20,000 pounds of hexadecanol had been added to Lake Hefner by the 16th of August, we have chosen that data to observe if any alterations had occurred in the general chemical-physical picture. Table 16, when compared to Table 11, shows no basic changes, excepting a lowering of the surface of the thermocline. In the early study period the thermocline started around 17 meters. On August 15 the thermocline surface was about 20 meters. The thermocline proper was only 4 meters deep on the latter date, the lower 2 meters forming the hypolimnion. It is possible that the two sets of samples

Table 14. --Plankton Count Record.

OKLAHOMA CITY EVAPORATION CONTROL STUDY
1958
LAKE HEFNER

Plankton Count

Station 1-Surface **Sample Volume** 1,000 ml. **Concentrated to** 10 ml. **Factor** 100

Collected by Limnology group **Date** June 25-July 9 **Temp. °C.**

Examined by Limnology group **Raw T.O.** 1 **Tap T.O.** 1

Wind: Direction South **Velocity** Variable **Air Temp. °F.** 68-92 **Sessile Algae** sparse

Pounds of Hexadecanol Placed on Lake Last 24 Hours None **Last Week** None

Film Present **Film Absent** X **(Check one) Hexadecanol on Shoreline** None during this study

GENUS and SPECIES	AVERAGE SURVEY	1	2	3	4	5	6	~~7~~ AVG.	8	9	10	COUNT
CHLOROPHYTA												
Ankistrodesmus	3.6			Closterium				10.0				
Protococcus	9.9			Sphaerocystis				1.0				
Quadrigula	.8											
Pandorina	12.0											
Gloeocystis	11.3											
Scenedesmus	12.0											
Crucigenia	6.3											
Cosmarium	8.2											
Chlorella	.66											
Pediastrum	9.5											
Chlamydomonas	.2											
Staurastrum	.66									Total		[illegible].12
EUGLENOPHYTA												
Euglena	4.0											
Trachelomonas	7.6											
Phacus	4.2									Total		15.8
CHRYSOPHYTA												
Tribonema	.2									Total		.2
XANTHOPHYCEAE												
BACILLIARIOPHYCEAE												
Navicula	6.3											
Melosira	.66											
Cyclotella	6.6											
Synedra	3.9											
Fragilaria	.2											
Nitschia	.5									Total		18.16
PYRROPHYTA												
Peridinium	1.5											
Ceratium	5.3									Total		6.8
CYANOPHYTA												
Coelosphaerium	.33			Anabaena				.33				
Merismopedia	3.8											
Microcystis	4.3											
Chroococcus	53.3											
Aphanizomenon	1.1											
Anabaenopsis	2.6									Total		65.76
OTHER ORGANISMS												
Keratella	25.0											
Difflugia	4.0											
Vorticella	2.0									Total		31.0
TOTAL ORGANISMS												223.84
AMORPHOUS												

Table 15. --Fish Record.

FISHERIES

LAKE HEFNER

TOTALS: JULY 4-7, 1958

Species	Total No.	Total wt. (kg)	Avg. wt. (gm)	Avg. Length (cm)	% of Total by No.	% of Total by wt. (gm)
White bass	9	5.016	557.5	30.85	1.057	3.16
Long nose gar	2	1.816	908.0	61.0	0.235	1.15
Shad	333	32.919	113.32	23.2	39.085	20.70
E. carp	54	19.364	528.0	32.9	6.338	12.18
R. carp	114	44.918	460.9	30.95	13.381	28.23
Drum	80	4.355	55.61	18.89	9.390	2.73
White crappie	139	11.844	86.4	13.42	16.314	7.42
Channel cat	121	38.864	290.8	31.40	14.201	24.43
TOTALS	852	159.096			100.000	100.00

secured from Station 1 were not from the same specific area, since wave action frequently moved the boat and we did not have any buoys as permanent markers. We could have been on the edge of the deep water rather than in the center. This is not an important item, however, since a general perusal of the data indicates no changes in the water quality.

Thermal stratification in Lake Hefner ordinarily terminates near the first of September, after which time the lake remains homothermous until the period of summer stagnation the next year. Table 17 shows the physical-chemical data secured on September 26, which indicated a homothermous condition as well as an almost homosaline situation from surface to bottom. It is apparent that during the turnover the minerals are more evenly distributed throughout the lake, and it would appear that the water quality actually improves. In the instance shown in Table 17, the dilution of the minerals may be attributed to the addition of water to Lake Hefner. It is concluded from the observations throughout the summer and fall that hexadecanol had no deleterious effect on chemical quality of the water. It is recalled that this study continued through the last of October. However, the general conditions found in September were altered only be a lowering of the temperature with no other obvious changes.

2. Plankton Studies

During the early study period, plankton counts were made from the surface, middle, and bottom at Station 1 and from the surface at the other stations. Table 14 represents the conditions that existed prior to the time hexadecanol was added to Lake Hefner. Continued observations were made by Mr. McReynolds in order to discern any changes that might be unusual in the general plankton picture of Lake Hefner. Since the hexadecanol formed numerous strings, and in many instances sank beneath the surface of the water, the effects of this material as a nutritional stimulant for general planktonic development could be readily studied. In addition, the southerly winds produced a rather heavy deposit of hexadecanol around the perimeter of the lake. From time to time the changing winds produced wave action, which washed over the deposited hexadecanol. This afforded an excellent opportunity for observations regarding the effects of this compound as a fertilizer for various types of biota. Since mention has previously been

Table 16. --Physical and Chemical Data Record.

Station 1

Date August 15, 1958

Time 5:00 p.m.

OKLAHOMA CITY EVAPORATION CONTROL STUDY
1958
LAKE HEFNER

Physical, Chemical Data

Records by J. K. G. Silvey,
John Goodman, Stanley Sissom

Parts Per Million or Mg. Per Liter

Sky Broken

Wind 10 kts.

Air Temp.

Depth M	Temp. C°	Spec. Cond.	pH	CO_3	HCO_3	SO_4	Cl	Hard. $CaCO_3$	O_2	CO_2
1	30.55	650	8.8	8.0	179.0	105.0	85	192	8.2	0
2	30.55	650								
3	30.55	650								
4	30.00	650								
5	28.85	650								
6	28.3	650								
7	27.5	650								
8	27.2	650								
9	26.9	650								
10	26.6	650								
11	26.6	650								
12	26.6	650	8.4	2.0	196.0	100.0	87.5	196	5.8	0
13	26.6	650								
14	26.6	650								
15	26.6	650								
16	26.6	650								
17	26.6	650								
18	26.4	650								
19	26.1	650								
20	25.0	675								
21	23.3	675								
22	19.4	675								
23	17.7	675								
24	17.2	700	7.9	0.0	228.0	100.0	90.0	208	0.4	3.0
25										
26										

Table 17. --Physical and Chemical Data Record.

Station 1
Date Sept. 26, 1958
Time

OKLAHOMA CITY EVAPORATION CONTROL STUDY
1958
LAKE HEFNER

Physical, Chemical Data

Records by J. K. G. Silvey,
John Goodman, Stanley Sissom

Sky Clear
Wind 15 kts.
Air Temp.

Parts Per Million or Mg. Per Liter

Depth M	Temp. C°	Spec. Cond.	pH	CO_3	HCO_3	SO_4	Cl	Hard. $CaCO_3$	O_2	CO_2
1	24.4	625	8.7	14	147	100	77.5	190	8.0	0
2	24.4	625								
3	24.4	625								
4	24.4	625								
5	24.4	625								
6	24.4	625								
7	24.4	625								
8	24.4	625								
9	24.4	625								
10	24.4	625								
11	24.4	625								
12	24.4	612								
13	24.4	612								
14	24.4	612								
15	24.4	612								
16	24.4	612								
17	24.4	612								
18	24.4	612								
19	24.4	600								
20	24.4	600								
21	24.4	600								
22	24.4	600								
23	24.4	600	8.65	18	145	90	79.8	184	7.0	0
24										
25										
26										

Table 18. --Plankton Count Record.

OKLAHOMA CITY EVAPORATION CONTROL STUDY
1958
LAKE HEFNER

Plankton Count

Station 1 (surface) Sample Volume 250 Concentrated to 5 Factor 4
Collected by E.E.H.-J.S.M. - O.C. Water Dept. Date 8/14/58 Temp. °C. 29.5
Examined by J.S. McReynolds - O.C. Water Dept. Raw T.O. 3 Tap T.O. 1
Wind: Direction SE Velocity 2 mph Air Temp. °F. 81 Sessile Algae Spotted
Pounds of Hexadecanol Placed on Lake Last 24 Hours 500 # Last Week 4,750 #
Film Present Film Absent X (Check one) Hexadecanol on Shoreline None

GENUS and SPECIES		AREAL STANDARD UNITS										
	SURVEY	1	2	3	4	5	6	7	8	9	10	COUNT
CHLOROPHYTA												
Closterium		1										4
Ankistrodesmus		1										4
Planktosphaeria		2										8
Chlamydomonas		1	2									12
Gonium			4									16
Pandorina			1	2								12
Phacetus				1		1						8
Chlorococcum				1	1							8
Pediastrum					5							20
EUGLENOPHYTA												
CHRYSOPHYTA												
XANTHOPHYCEAE												
BACILLIARIOPHYCEAE												
Melosira				1								4
Cyclotella				1								4
Synedra						1						4
PYRROPHYTA												
Ceratium				1								4
CYANOPHYTA												
Aphanizomenon		4	4	5	9	3						100
Aphanocapsa					3							12
OTHER ORGANISMS												
Polyarthra	F											
Pedalion	F											
Keratella	P											
Verticella	P											
Difflugia	P											
Conochilus	P											
Phascoledon	P											
TOTAL ORGANISMS		36	44	48	72	20						220
AMORPHOUS		325	300	300	300	350						

P - Present
F - Few

Table 19. --Plankton Count Record.

OKLAHOMA CITY EVAPORATION CONTROL STUDY
1958
LAKE HEFNER

Plankton Count

Station 1 (Surface) Sample Volume 250 Concentrated to 5 Factor 4

Collected by I.W.H.-J.S.M.- O.C. Water Dept. Date 9/5/58 Temp. °C. 26

Examined by J.S. McReynolds- O.C. Water Dept. Raw T.O. 8 Tap T.O. 2

Wind: Direction SE Velocity 10 mph. Air Temp. °F. 83 Sessile Algae Growing

Pounds of Hexadecanol Placed on Lake Last 24 Hours None Last Week 3,925

Film Present Film Absent X (Check one) Hexadecanol on Shoreline Hexadecanol above water level

GENUS and SPECIES		AREAL STANDARD UNITS										
	SURVEY	1	2	3	4	5	6	7	8	9	10	COUNT
CHLOROPHYTA												
Chlamydomonas		4	6	3	2							60
Staurastrum		3										12
Closterium		1										4
Schroedaria			1									4
Chlorococcum						1						4
EUGLENOPHYTA												
CHRYSOPHYTA												
XANTHOPHYCEAE												
BACILLIARIOPHYCEAE												
Melosira		1			2							12
Cyclotella		1	1	1	1	2						24
PYRROPHYTA												
CYANOPHYTA												
Oscillatoria		2	21	43	14	1						324
Aphanizomenon		2	2	1	3	2						40
Polycystis		2										8
Anabaena			2			3						20
Aphanocapsa				2								8
OTHER ORGANISMS												
Nauplius	P											
Polyarthra	P											
Keratella	P											
TOTAL ORGANISMS		64	132	200	88	36						520
AMORPHOUS		275	300	300	300	300						

P - Present

Table 20. --Plankton Count Record.

OKLAHOMA CITY EVAPORATION CONTROL STUDY
1958
LAKE HEFNER

Plankton Count

Station **1 (Surface)** Sample Volume 250 Concentrated to 5 Factor 4

Collected by **E.E.H.-J.S.M.- O.C. Water Dept.** Date 9/25/58 Temp. °C. 24.5

Examined by **J.S. McReynolds- O.C. Water Dept.** Raw T.O. 4 Tap T.O.

Wind: Direction **W NW** Velocity 6 mph. Air Temp. °F. 80 Sessile Algae **Growing**

Pounds of Hexadecanol Placed on Lake Last 24 Hours **None** Last Week **1,200 #**

Film Present Film Absent X (Check one) Hexadecanol on Shoreline **Hexadecanol above water level**

GENUS and SPECIES	AREAL STANDARD UNITS											
	SURVEY	1	2	3	4	5	6	7	8	9	10	COUNT
CHLOROPHYTA												
Chlamydomonas		1	1		1							12
Schroederia			1									4
Staurastrum				6								24
Pediastrum				11								44
Closterium				1	2	5						32
Phacotus				1	1							8
Dimorphococcus				1								4
Oocystis						1						4
Coelastrum						4						16
EUGLENOPHYTA												
CHRYSOPHYTA												
XANTHOPHYCEAE												
Botryococcus			4	1	2	1						32
BACILLIARIOPHYCEAE												
Cyclotella		5	3	5	4	6						92
PYRROPHYTA												
CYANOPHYTA												
Aphanizomenon		1		4		16						84
Polycystis		1	3		12							64
Aphanocapsa		1	5	2								32
Anabaena			13			5						72
Oscillatoria					7							28
OTHER ORGANISMS												
Bosmina	F											
Nauplius	F											
Synchaeta	P											
Vorticella	P											
Noteus	P											
TOTAL ORGANISMS		36	120	128	116	152						552
AMORPHOUS		350	350	350	350	350						

F - Few
P - Present

made concerning the physical-chemical conditions on Lake Hefner on or near the middle of August, it is proper to include a plankton count taken from the surface of Station 1 on or about the same date. The areal standard units were about the same as those obtained in late June and early July, and the composition of organisms had altered only slightly from the situation at an earlier time (Table 18). The fall turnover in Lake Hefner occurred before September 5, and a plankton pulse became evident in a short time. Table 19 shows the areal standard units at Station 1, which represented a definite increase in a period of about 3 weeks.

The problem of plankton blooms in Southwestern reservoirs has been studied in meager detail. One reservoir does not appear to duplicate another, either in the prevalence of organisms or in the quality of the population. On the surface it might appear that the hexadecanol was responsible for producing the increase of organisms in Lake Hefner, with special reference to the blue-green algae. We are all aware that this particular group may prove detrimental to a water supply because of the high protein content and the availability of the nutrients in these organisms to the taste and odor producing actinomycetes. Fortunately, data are available over a number of years for Lake Hefner so that conclusions may be readily drawn concerning the situation in 1958 as compared to previous years. Since the greatest bloom of algae occurred on September 25, 1958, at Station 1, let us consider Table 20 and assume that by comparing these data with those of previous years, we may come to some conclusions regarding the effects of the hexadecanol as a source of nutrition for planktonic forms.

Table 21

Dates	Plankton ASU - Hefner	Plankton ASU - Overholser
9/22, 28/53	190	17,040
9/27, 28/54	332	528
9/28, 27/55	428	88
9/25, 24/56	144	448
9/26, 25/57	152	172
9/25, 23/58	552	340
Average Plankton - ASU	299	3,103

If reference is made to Table 21, one may review the A.S.U. of the plankton crop in late September in Lake Hefner for the past 6 years. The average A.S.U. counts, including 1958, were 299. We observe that during 1958, therefore, the A.S.U. count was somewhat higher than the average for the years cited. We are mainly interested, however, in the blue-green algae. During the periods mentioned above, the A.S.U. count for the blue-green algae averaged 250; while for 1958, it was 280. It would not appear from these considerations that hexadecanol might be readily utilized by this group of organisms. It is probably more conclusive to compare these data with those from Lake Overholser for similar dates. One may recall that this lake was not treated with hexadecanol; and although it is situated on the bypass of the North Canadian River, the water it receives is somewhat similar to that found in Lake Hefner. To be sure, on occasions it would receive water of greater fertility; and at other times, very muddy inflowing water might reduce the plankton count to a low concentration. The average for the same period in Overholser in A.S.U. counts was 3,636, of which the majority was due to the bloom of blue-green algae during the year of 1953. Had this bloom occurred on Hefner in 1958, we might have some reason to presume a fertilizing effect from hexadecanol. Other conditions being equal, however, it would appear that the utilization of this compound is not accomplished directly by normal planktonic biota to any noticable extent.

It is noteworthy that the hexadecanol deposited around the perimeter of Lake Hefner is still somewhat persistent. On January 21, 1959, we made a survey of the shoreline of Lake Hefner, which revealed deposits of the material still available in those areas. Prior to the end of the growing season we did note that certain sedges grew more profusely in and around the hexadecanol deposits. Ordinarily this would not be of any particular concern since these plants frequently are found above and below the water line in Southwestern reservoirs. In Lake Hefner, however, the occurrence of dense growths of sedges, particularly in the fall, is considered undesirable because these types of vegetation may serve admirably for nutrient sources for the taste and odor producing actinomycetes. One other observation regarding the general biology of Lake Hefner revolves around the accumulations of hexadecanol and inflorescense from submerged, floating, and emergent types of vegetation. The floating mats of vegetative material, mixed with the hexadecanol, were carried shoreward and ultimately deposited either on the riprap or the muddy shoreline of the lake. Invariably these areas contained unusual zones of actinomycete activity and consequently were sources for the production of taste and odor compounds. It should be recalled that such areas are only of importance when they become submerged due to rising water levels or more especially when rainfall occurs so that the inflowing water from such contaminated regions adds odoriferous products to the surface waters. It is possible that the bacteria growing on the hexadecanol may have made compounds available, which along with the entangled vegetation resulted in the copious growths of the actinomycetes. It is proper to conclude that actinomycetes may otherwise grow around the perimeter of Lake Hefner, but the precautions taken in chemical treatment during 1956-57 subdued the growth to a minimum. The same treatment in 1958, however, did not appear to have a deleterious effect on the odor producing organisms growing on the admixture of vegetation and hexadecanol.

3. Bacteria

During the early study period the bacterial counts, except for the bottom areas, at the five stations on Lake Hefner were reasonably low. Following the addition of hexadecanol, the bacterial population began to increase (Figure 14). The organisms to respond first were *Aerobacter* sp., which attained their maximum concentration sometime between August 17 and August 29. Since the samples for bacterial studies were taken at approximately 2-week intervals, the amount of hexadecanol added is shown in the block columns on a basis similar to the sampling schedule. The density of the population was not maintained due to the reduction in availability of the hexadecanol so that in a period of 2 weeks *Aerobacter* sp. diminished to a low concentration. *Pseudomonas* sp. began to respond to the nutrients in the hexadecanol soon after the original additions were made and attained a maximum population sometime between August 30 and September 12. The population diminished more slowly than *Aerobacter* sp., almost disappearing by the latter part of September. *Alcaligenes* sp. responded more slowly than *Pseudomonas* sp. but attained a maximum concentration at a similar time. The last group of bacteria to show a definite increase were the *Bacillus* group, containing several species; and it is possible that *Flavobacterium* sp. was a member of the group since several pigmented forms appeared in samples taken in July and August. 21/ No attempts at detailed identification were made in this study. The maximum population in the *Bacillus* group was attained near the middle of September, followed by a disappearance on or about the last of October.

The limnetic distribution of the different genera of bacteria was interesting since certain stations showed an even distribution from surface to bottom, while others very obviously had a greater concentration near the surface or near the bottom. If then any specific bacterial population obtained concentrations in excess of 1 million organisms per milliliter on either the surface or the bottom, they were also cultured from the middle. Samples collected on August 29 and September 12 showed the greatest density in population. *Pseudomonas* sp. attained counts in excess of 4 million per milliliter, as did *Aerobacter* sp. and *Alcaligenes* sp. The actinomycetes did not exceed 300 thousand, and this was at one station on August 29. The rate of growth of the micro-organisms in Lake Hefner resembled very closely the laboratory findings that have been carried on at North Texas State laboratories during the past 2 years. 22/ Under optimum conditions it appears that most of the bacteria encountered reached a maximum population in approximately 6 weeks. Normally they will increase from 10 organisms per milliliter to as many as 10 million in that period of time. If hexadecanol is continued as a source of nutrition, maintenance of the population appears very good. If the hexadecanol is removed, there is an obvious and rapid decrease in organisms. This is usually accomplished in a period of 3 weeks. It is therefore noteworthy that by the last of October the bacterial counts had decreased to a very low concentration; and by November 15, were lower than they were during the first week of July.

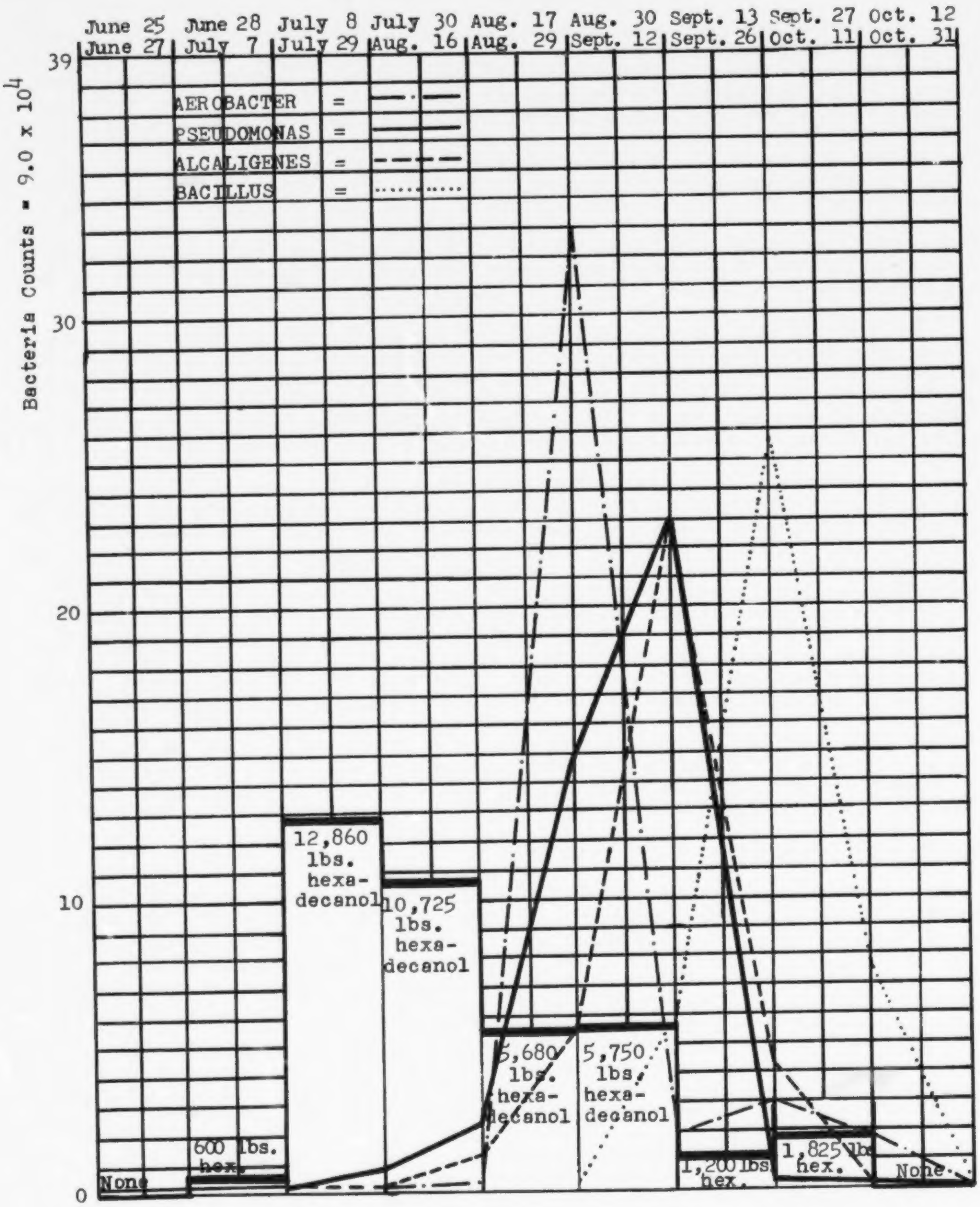

Figure 14. --Relation of hexadecanol added in intervals of 2-week periods to the total colony counts of organisms during the same period(s).

The total bacteria count, including all genera as well as actinomycete spores, at certain stations on Lake Hefner rose to a level of 15 million per milliliter. Figure 14 is an average count of all stations and all levels, including samples collected at top, middle, and bottom and therefore does not reveal maximum concentrations. Raw water entering the Lake Hefner filtration plant showed counts as high as 10 million bacteria per milliliter of the collective genera. While these organisms may not be of public health importance, it must be concluded that the chlorine demand would of necessity be increased. Studies on the finished water during the same period--late August to early September--showed bacterial counts of 1,000 per milliliter. Admittedly, the Lake Hefner Water Plant was doing a fair job in reducing the bacterial population. Possibly these results indicate further studies on water supply reservoirs before hexadecanol is approved for such use, since only a few genera were isolated from the waters of Lake Hefner and in one instance different from those in the Cincinnati region.

It should be mentioned that in the latter part of August studies were also made on Lake Overholser from the standpoint of bacterial population, and it was found that the same genera of organisms were available in the raw water although their concentrations did not exceed 1,600 per milliliter. It would appear rather conclusive that hexadecanol contributed to the growth of the organisms mentioned; and had the monolayer been maintained continuously, doubtless the concentration of bacteria would have been higher.

Preparatory to the Lake Hefner experiment, a request was made to the Robert A. Taft Sanitary Engineering Center to procure samples of the carbon removed from the filters on the raw water intake and finished water outlet from the Lake Hefner plant. In compliance with our request, samples were forwarded to us, and they were studied from the standpoint of bacterial population. Granules of carbon from the raw water filters were placed on slightly warm tryptocase-soy agar and observed for bacterial growth. At the same time selected granules of carbon were aseptically placed in 100 milliliter samples of sterile water. The samples were agitated on a shaker for 1 hour and subsequently plated on similar media. The same procedure was followed in regard to the carbon samples taken from the finished water. At the same time one or two carbon granules were placed in thioglycollate broth in order to obtain organisms for identification. The carbon granules from the raw water filter had the same genera of organisms that were present in the lake; and as far as we could ascertain, the average-sized granule of carbon in 100 milliliters of sterile water liberated approximately 2-1/2 million organisms per milliliter. The carbon from the finished water liberated approximately 10,000 organisms per milliliter.

4. Residual Hexadecanol

It has previously been stated (page 61) that the hexadecanol deposited around the perimeter of Lake Hefner is somewhat persistent. Observations of the shoreline on January 21, 1959, revealed that deposits of hexadecanol resulting from the treatments made between July 3 and October 1, 1958, still existed. Consequently, observations were continued and on April 3, 1959, it was noted that the apparent quantities of the material (at that time, well above the waterline) appeared basically the same as they did in January and in apparently the same concentration as noted in October 1958. Although the locations of these deposits were not plotted on maps nor were specific weights of these deposits determined, rather detailed field notes describing the deposition of hexadecanol in particular areas of the shoreline and the extent of this coverage are sufficiently accurate for statements to be made concerning the persistence of this compound.

Since the April 3 observation, water has been introduced into Lake Hefner so as to inundate a portion of the deposits. Percentagewise, more of the residual hexadecanol was under water than was above water. This is because, during the time of application, the surface level of Lake Hefner was decreasing; and, dependent upon the quantities of hexadecanol added, variable deposits accumulated. On May 1, 1959, it was observed that a small portion of the hexadecanol broke loose and appeared as granules or flakes floating on the surface of Lake Hefner. The major underwater deposits had not yet broken loose. It would, therefore, appear that the quantities deposited in the summer and early fall remain intact and are not greatly reduced. From past experience, it could be assumed that the hexadecanol now inundated will probably be consumed by biologic activity. When the water temperature increases, actinomycete counts being made continuously on the waters of Lake Hefner may readily reveal the importance of this organic matter in the biotic cycles of the lake.

It is highly probable that the observations made on the deposition of hexadecanol in Lake Hefner are inadequate. This statement is made in light of the direction of the prevailing winds and the construction of the dam for the impoundment. A considerable proportion of all hexadecanol blown from Lake Hefner accumulated on or in the riprap of the dam. The deposited hexadecanol ultimately was moved by wave action into the spaces between the rocks composing the riprap and, therefore, was not visually apparent. Due to this fact, observations were possible only on the shoreline composed of soil, which is on the east, south, and a small portion of the west sides of the lake. Since the prevailing winds were southerly, southwesterly, or easterly, a high percentage of the total material deposited around the lake margin could not be observed. It could be assumed, however, that the hexadecanol deposited in the riprap remains available to furnish nutrients for numerous micro-organisms in Lake Hefner.

Possibly, a continued study of not only actinomycetes, but bacterial populations, is in order if the final biologic picture of hexadecanol in a monolayer as well as in a residual form is to be known. The waxy consistency of the hexadecanol has not changed perceptibly, although it is apparent from placing it in a water solution that the outside portion has degraded to weak acids that are slowly miscible in water and which, on extraction with chloroform, show numerous weak acid groups on the infrared spectrophotometer. From this, it can be assumed that the hexadecanol per se probably will not again be available to form a monolayer since it will probably degrade into some similar weak organic acids, as the acids are consumed by micro-organisms. Just how much of a problem might result in the control of the organisms that consume deposits of slightly oxidized hexadecanol remains to be ascertained.

At present, it appears that the destruction of hexadecanol by bacteria is more of an economic problem than a public health consideration. After the water attains a temperature of 26° C., the amount of hexadecanol required by the bacteria appears to increase in a geometric ratio. Consequently, during the first 3 weeks of application the bacteria in any given area appear to require an amount of hexadecanol equal to the quantity demanded to cover that area of water. During the next 3 weeks, twice the amount is demanded. During the third 3 weeks, four times the amount is demanded, and so on throughout each similar period. The most encouraging observation appears to be the rapid loss of bacteria from the water when the hexadecanol is removed. Again, this period appears to be approximately 3 weeks. Consequently, if economics is an important phase in the problem of evaporation control, hexadecanol should probably be added for a period of 6 weeks followed by 3 weeks of remission with a repeated application. This is assuming, of course, that the various disinfecting agents that have been investigated and those that will be later investigated fail to reduce the bacteria to a minimum concentration. 21/

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22. Hinckley, Nelda. "Bacterial Degradation of Hexadecanol." Master's Thesis. North Texas State College, Denton, Texas. 1957.

LAKE HEFNER TESTS

REPORT ON ATTEMPTED RECOVERY OF HEXADECANOL

--from Ralston Reservoir, Denver, Colorado, and Lake Hefner, Oklahoma City, Oklahoma

By F. M. Middleton

U. S. Department of Health, Education, and Welfare
Public Health Service
Robert A. Taft Sanitary Engineering Center

REPORT ON ATTEMPTED RECOVERY OF HEXADECANOL
from Ralston Reservoir, Denver, Colorado and Lake Hefner, Oklahoma City, Oklahoma

BACKGROUND

As its contribution to the comprehensive study by representatives of State and Federal agencies collaborating on the Lake Hefner evaporation reduction investigations by the use of hexadecanol monolayers, the Public Health Service attempted to recover hexadecanol applied to Ralston Reservoir, Denver, Colorado (Summer, 1957), and Lake Hefner, Oklahoma City, Oklahoma (Summer, 1958). Raw water from Ralston Reservoir and raw and treated water from Lake Hefner were sampled.

SAMPLING METHOD AND ANALYSIS

The carbon filter was used for sampling. The method consists of running several thousand gallons of water through a tube of activated carbon. The organic contaminants, including the hexadecanol, if present, are adsorbed onto the carbon. The organics are extracted from the carbon with chloroform. An alcohol extraction of the carbon is also made. The alcohol recoverable materials are not pertinent to this study.

Upon separation into chemical groups, it has been found that the hexadecanol goes into the oxygenated fraction. Complexing of this fraction with urea removes the hexadecanol from other oxys. The hexadecanol is recovered from the complex and is analyzed by infrared. Under the conditions of the tests on the Ralston Reservoir and at Lake Hefner, the sensitivity of the test was about 5 μg/1 (5 parts per billion). The effectiveness of the sampling and recovery procedure was tested in the laboratory using known samples.

RALSTON RESERVOIR STUDY

Samples were collected at the discharge end of Gross Reservoir, which feeds the Ralston Reservoir, and at the discharge end of Ralston Reservoir. Three sets of samples were collected from these sampling points.

The first series was collected before application of hexadecanol. The last two series were collected during the period of hexadecanol application to Ralston Reservoir. The chemical characteristics of the third series did not appear different from the second series; hence the third series was not examined in detail. Data from the two samplings are shown in Table 22. The values obtained upon analysis of samples from Gross and Ralston Reservoirs are in good agreement. No difference due to hexadecanol is obvious. The materials recovered appear to be natural to the reservoirs. The infrared spectra of the recovered fractions were obtained to determine if hexadecanol appeared as a component. None could be detected. It is concluded that hexadecanol, if present, occurred in concentrations of less than 5 μg/1.

LAKE HEFNER STUDY

Raw and finished water samples were put through filters during the application of hexadecanol. The method of sampling and analysis was the same as the method used on the Ralston Reservoir. No hexadecanol could be detected in the raw or finished water. If the compound was present, the concentration was less than 5 $\mu g/1$. The chemical analyses of the samples are given in Table 23.

Since Lake Hefner has been of considerable interest from the standpoint of tastes and odors, it seemed desirable to examine the carbon filter data further. The recovery of the 125 ppb of chloroform extractable materials from the raw water is of interest. A carbon filter operated on the Lake Hefner supply during the period of August 18 to November 2, 1955, showed only 40 ppb of chloroform extractables. No continuous data are available to indicate whether the increased amount of organics is a trend or just an isolated happening. There is no evidence that the high recovery is due to hexadecanol. Our National Water Quality Basic Data Program shows that relatively unpolluted waters usually contain less than 50 ppb of chloroform extractables as measured by the carbon filter. The finished Oklahoma City water contained 32 ppb of chloroform extractables indicating a 75 percent reduction of organics through the water treatment plant. This is an unusually high reduction compared with many water plants. Frequently no reduction in organics occurs as a result of water treatment. It can be assumed that hexadecanol, if present in the raw water, would be reduced an equal amount.

CONCLUSIONS

No hexadecanol could be detected in the raw water from Ralston Reservoir and the raw and finished water from Lake Hefner by use of a method sensitive to a concentration of 5 ppb of hexadecanol. Analysis was performed by Mr. Lee Musgrave.

Table 22.--Ralston Reservoir Study, Carbon Filter Data.

	Before hexadecanol application				During hexadecanol application			
Sampling point	From Gross Res. to Ralston Res.		Exit from Ralston Res.		From Gross Res. to Ralston Res.		Exit from Ralston Res.	
Date of run	7-25 to 8-2-57		7-25 to 8-5-57		8-29 to 9-5-57		8-29 to 9-5-57	
Gallons filtered	5,000		3,871		4,439		2,366	
Organics Recovered	ppb	%	ppb	%	ppb	%	ppb	%
Chloroform	53		78		54		75	
Alcohol	104		204		127		236	
Total	157		282		181		311	
SEPARATION OF THE CHLOROFORM EXTRACT								
Ether insolubles	2	3	3	4	2	3	2	3
Water solubles	17	33	24	31	18	24	28	37
Neutrals	8	15	10	13	7	13	17	22
CHROMATOGRAPHIC SEPARATION OF THE NEUTRALS								
Aliphatics	(2)	(18)	<(1)	(5)	(1)	(20)	(1)	6
Aromatics	<(1)	(9)	<(1)	(5)	<(1)	(5)	>(1)	5
Oxys	(7)	(81)	(9)	(88)	(5)	(76)	(10)	59
Loss	<(1)	(8)	<(1)	(2)	(1)	--	(5)	31
Weak acids	4	8	12	15	5	10	8	10
Strong acids	5	9	11	14	3	6	7	9
Bases	<1	1	3	4	1	1	5	6
Loss	16	31	15	19	17	31	10	13

Table 23. --Lake Hefner Study, Carbon Filter Data From Raw and Finished Water During Application of Hexadecanol.

Sampling point	Raw water		Finished water	
Date of run	8-4-58 to 8-11-58		8-4-58 to 8-11-58	
Gallons filtered	5,376		5,481	
Organics recovered	P.P.B.	%	P.P.B.	%
Chloroform extract	125		32	
Alcohol extract	125		110	
Total				
	Separation of the chloroform extract			
Ether insolubles	20.0	16.0	0.6	2.0
Water solubles	28.4	22.7	8.0	25.1
Neutrals	23.5	18.8	12.8	40.4
	Chromatographic separation of the neutrals			
Aliphatics	(2.3)	(9.9)	(2.2)	(17.0)
Aromatics	(1.1)	(4.8)	(0.9)	(6.9)
Oxys	(15.5)	(65.9)	(6.4)	(50.2)
Loss	(4.6)	(19.4)	(3.3)	(25.9)
Weak acids	8.4	6.7	1.5	4.6
Strong acids	11.0	8.8	0.7	2.2
Bases	1.6	1.3	0.9	2.8
Loss	32.1	25.7	8.5	22.9

LAKE HEFNER TESTS

EVALUATION OF HEXADECANOL FORMULATIONS CONTAINING VARIOUS DISINFECTING AGENTS IN EVAPORATION REDUCTION

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Public Health Service
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EVALUATION OF HEXADECANOL FORMULATIONS CONTAINING VARIOUS DISINFECTING AGENTS IN EVAPORATION REDUCTION

During the summer of 1958, studies were conducted at the Sanitary Engineering Center to determine the feasibility of including a bactericide in a hexadecanol formulation to prolong the life of the film developed on a water surface for suppression of evaporation. The economic value of controlling biological growths causing degradation of the hexadecanol and interfering with maintenance of the monomolecular film had been indicated by the laboratory work of Ludzack and Ettinger 24/, and field studies conducted by the Bureau of Reclamation 23/, 25/, and the Southwest Research Institute 26/. It is also noted that Silvey 23/ observed a marked increase in Pseudomonas population occurred in Kids Lake during the use of hexadecanol.

These investigations included studies of (1) physical characteristics of hexadecanol film formation, (2) film pressures developed by various hexadecanol film formulations, (3) laboratory bench experiments on savings in evaporation loss obtainable with various hexadecanol formulations, (4) outdoor stock tank evaporation investigations with selected hexadecanol formulations, (5) study of bacteria attacking hexadecanol, and (6) inhibiting effects of the various hexadecanol formulations on bacterial growth.

The potential toxicity to humans resulting from additives used in such formulations was not evaluated in these experiments. Such consideration is an essential preliminary to acceptance of any proposed additive. No attempt was made here to assess economic factors related to cost of chemicals, cost of application, and frequency of application.

A brief summary of the results of the studies follows:

1. Additional evidence has been obtained showing that the hexadecanol film promotes growth of the micro-organisms--Pseudomonas sp. and Flavobacterium sp. This growth is accompanied by destruction of the film, and interference with its repair.

2. Bactericidal compounds incorporated in hexadecanol formulations may prolong the effectiveness of the film. Such formulations should meet the following conditions:

   a. Have no significant toxicity for humans.

   b. Not reduce the film pressure significantly.

   c. Resist biological attack.

   d. Resist photochemical breakdown.

1. Physical Characteristics of Hexadecanol Film Formation.

a. Film-pressure-time relationship.

The formation of the film-spread from a 25 mm diameter pellet (78 mm water-contact perimeter) was studied at 25° C. by measurement of film pressure using a hydrophil balance. Results are shown in Figure 15. Measurable film pressure was first detected at 9 minutes. Thereafter it increased rapidly during the next 20 minutes and finally reached a state of equilibrium at 40.4 dynes cm^{-1} after approximately 50 minutes. That

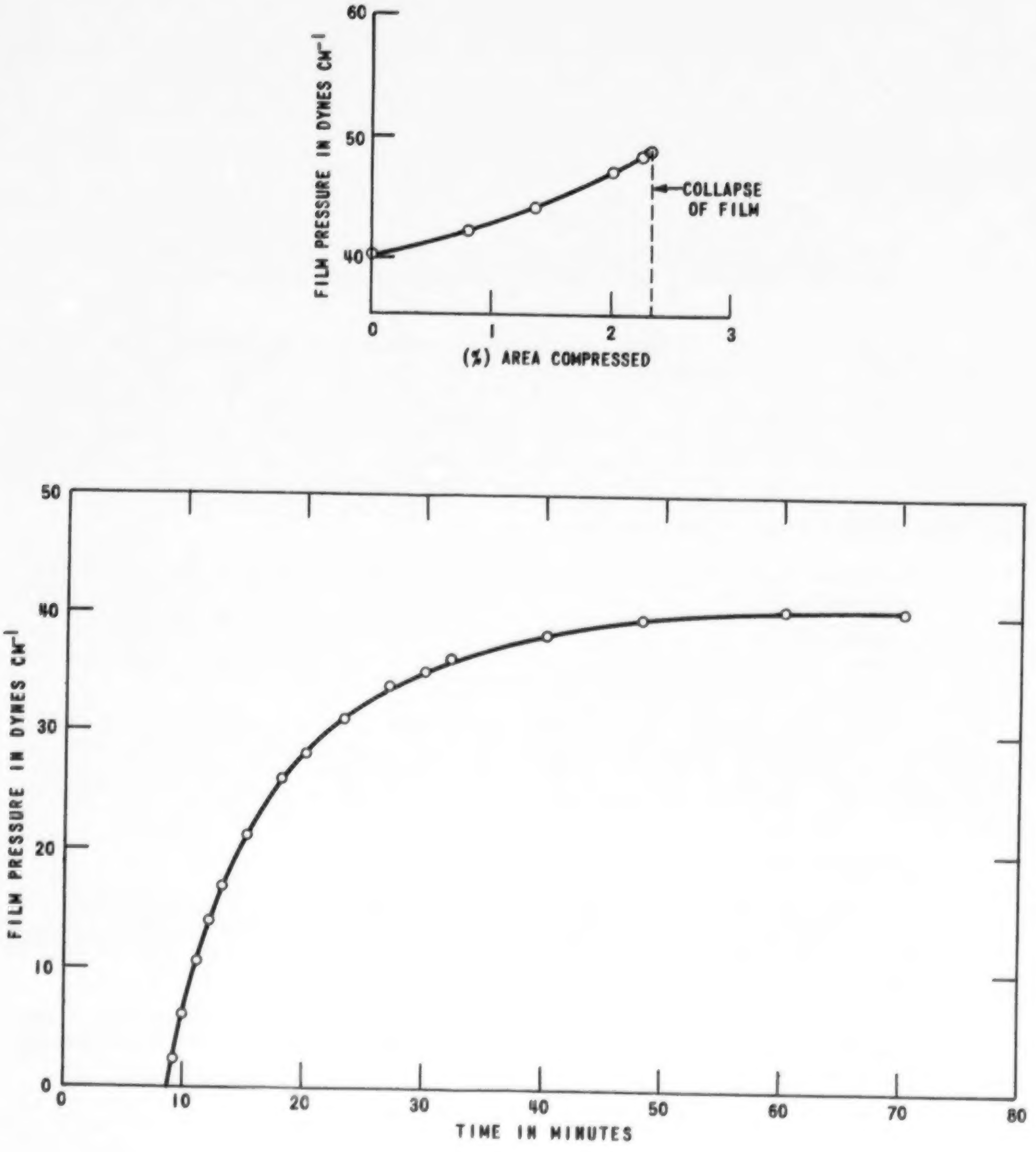

Figure 15. --Surface Pressure-time Relationship, and Compressibility of Hexadecanol Film on Water at 24.8° C.; Perimeter of Pellet - 78 mm Water Surface - 700 CM^2.

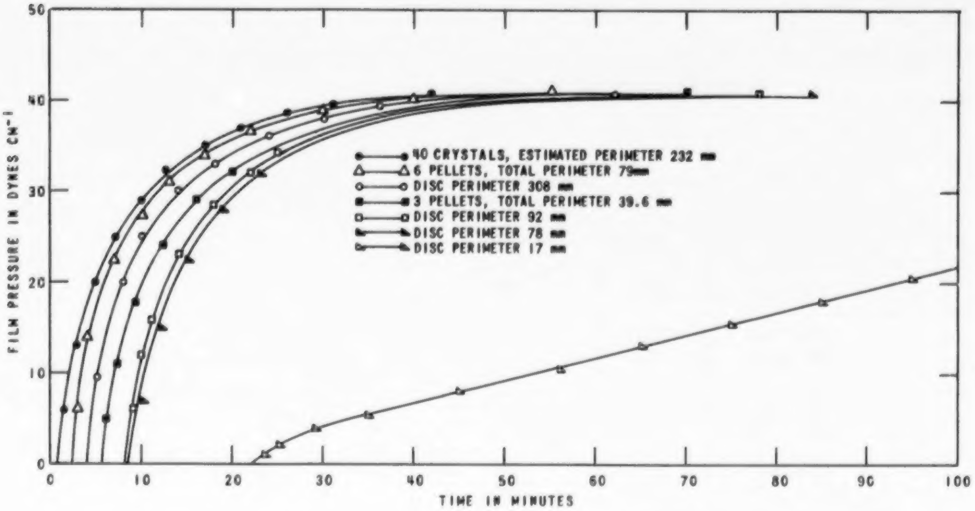

Figure 16. --Effect of Perimeter and No. of Spreading Sources on the Formation of Film From Hexadecanol Crystals and Discs of Various Sizes on Water at 24.8° C. (Water Surface - 700 CM^2).

such films are quite rigid is indicated by their collapse when a film is compressed to 97.7 percent of its original area. Film pressure at rupture was 48.6 dynes cm^{-1}.

b. Size and number of spreading sources.

A study was made of the effect of the number of sources and their water-contact perimeters on the rate of film formation. Results are shown in Figure 16. It was noted that the number of sources was an important factor. Therefore, the rate of film formation of a crystalline powder averaging approximately 0.1 mm in diameter was investigated. The results (not shown in Figure 16) were poorer than expected. This was probably due to the fact that the very small crystals floated on top of the water surface, providing a relatively small water-contact perimeter. It may be concluded that for a given weight of hexadecanol the particles applied should be the smallest size which provides the maximum water-contact perimeter. The diameter of such particles appears to be between 1 and 2 mm.

2. Film Pressures of Hexadecanol Formulations.

Equilibrium film pressures of hexadecanol and hexadecanol formulations are given in Table 24. All additives reduced the film pressure. Although it was recognized that such a decrease would result in a less efficient film for suppression of evaporation, it was assumed that the control of biological growths would prolong the useful life of the hexadecanol film and more than offset the reduction in film pressure.

3. Suppression of Evaporation Obtained with Various Hexadecanol Formulations.

Based on the results of preliminary studies, hexadecanol formulations containing the following additives were studied.

Additive type	Percent of mixture	Laboratory study	Outdoor study
None	None	x	x
None (Chlorinated H_2O)	None	x	
Tribromomelamine (TBM)	15	x	x
Trichloromelamine (TCM)	15	x	x
Hexachloromelamine (HCM)	15	x	x
Pentachlorophenol (PCP)	15	x	x
Benzylchlorophenol (BCP)	15	x	x
Dichlorochloroanilinotriazine (DCT)	15	x	x
Trichlorocarbonilide (TCC)	15	x	
Bithionol	15	x	x
Iodine (I_2)	2.5	x	x
	7.5	x	x

Table 24. --Film Pressures of Hexadecanol and of Hexadecanol-Formulations on Distilled Water at 25° C.

Hexadecanol	Additive		Film pressure (dynes/cm) at equilibrium and standard deviation
	Type	(%) of Mixture	
99% pure	None	---	40.4 ± 0.3
95% pure	None	---	40.4 ± 0.4
95% pure	TCM	5	38.1 ± 0.2
95% pure	TCM	15	37.2 ± 0.4
95% pure	HCM	5	38.2 ± 0.3
95% pure	HCM	15	36.8 ± 0.4
95% pure	TBM	5	38.5 ± 0.2
95% pure	TBM	15	37.6 ± 0.3
95% pure	I_2	2.5	36.8 ± 0.2
95% pure	I_2	5	36.1 ± 0.2
95% pure	I_2	7.5	35.0 ± 0.3
95% pure	I_2	10	34.2 ± 0.4
95% pure	TCC	5	38.7 ± 0.5
95% pure	TCC	15	38.0 ± 0.4
95% pure	Bithionol	5	38.9 ± 0.3
95% pure	Bithionol	15	38.1 ± 0.2
95% pure	PCP	5	39.0 ± 0.4
95% pure	PCP	15	38.2 ± 0.2
95% pure	BCP	5	38.9 ± 0.3
95% pure	BCP	15	38.2 ± 0.3
95% pure	DCT	5	38.8 ± 0.2
95% pure	DCT	15	38.1 ± 0.3
95% pure	Tyrothricin	5	35.0 ± 0.5

TCM - Trichlormelamine
HCM - Hexachlormelamine
TBM - Tribromomelamine
TCC - Trichlorocarbonilide
PCP - Pentachlorophenol
BCP - Benzylchlorophenol
DCT - Dichlorochloroanilinotriazine

In each case the hexadecanol, or hexadecanol formulation, was applied in the form of a coarse powder having particle sizes averaging about 1 mm in diameter.

a. Bench studies.

Bench studies were made at three different locations. Location I was chosen so that the air from the air-conditioning outlet wrinkled but did not break the water surface. At Location II a gentle breeze was produced over the water surface, and at Location III, the air movement was relatively unnoticeable.

These studies were conducted using small pails, 11 inch diameter, and pans, 10 inches long by 7 inches wide, filled to within 1/2 inch from the tops with distilled water inoculated with 2 ml settled sewage per liter. The hexadecanol formulations were applied at rate of 4 mg of hexadecanol per square foot. Two controls were used, one treated with hexadecanol, without additive, and the other a water blank. Duplicate pans or pails were used for each formulation and control. Evaporation losses were determined by measuring the volume of water required to bring the water level, as determined by use of a point gage, to its original elevation. The measured evaporation was corrected by a factor previously determined for each pan location on the bench. All pans and pails were emptied and carefully cleaned prior to each run.

Test results, expressed in percentage reduction of evaporation from untreated water surface, are summarized in Table 25. It is emphasized that the percent reductions appearing in this table are average daily reductions for the total test period. Average data from this table have been used to plot Figure 17.

These laboratory experiments indicate:

(1) The percent reduction in evaporation increases as the evaporation loss increases.

(2) That potential savings are possible if the biological life attacking the hexadecanol and interfering with film formation can be rigidly controlled as evidenced by the reduction obtained when hexadecanol only was applied on chlorinated water.

(3) That hexadecanol alone was most effective over a 2-day period. This is also supported by the decrease in measured film pressures obtained when a bactericide was incorporated in the hexadecanol formulation. It should also be noted that prior to each experiment, the pails and pans were carefully cleaned. If the water had been inoculated previously with heavy growths of bacteria attacking hexadecanol, this 2-day period might be substantially less.

(4) Hexadecanol formulations containing TBM, HCM, PCP, and BCP were the most effective in prolonging the life of the monomolecular film.

b. Outdoor studies.

Limited studies were conducted using the more promising hexadecanol formulations. These were made using six stock tanks, 4 feet in diameter and 20 inches deep. In each test, hexadecanol formulations were applied to two tanks; hexadecanol alone to two tanks; and two tanks were used to determine uncontrolled evaporation. Preliminary studies showed corrections of evaporation data for position of tank were unnecessary. Other test procedures were similar to those used in the bench studies.

Results are shown in Table 26. The TBM and HCM formulations, which had shown good reduction in evaporation losses in bench studies, were seemingly ineffective in outdoor studies. This is believed due to the exposure to sunlight decomposing these two compounds. The reverse was true with the I_2 formulations, which apparently released I_2 from the $(C_{16}H_{33}OH)_6 \cdot I_2$ complex. This provided disinfection and released the hexadecanol molecule to form a monomolecular layer of increased film pressure.

PCP and BCP formulations showed substantial reduction in evaporation in both bench and outdoor experiments. This may be attributed to their relatively high film pressures, fair bacteriostatic properties, and high stabilities.

c. Bacteriological study.

Microphotographs of the flora and fauna obtained during the laboratory studies by touching the water surface with a cover slip are shown in Figure 18. These indicate that a substantial accumulation of bacteria develops on clean water surfaces, and that in the presence of hexadecanol, this growth is accelerated. The presence of TBM, HCM, PCP, and BCP appears to retard such growths. Microscopic examination of samples from outdoor studies showed that PCP and BCP formulations were effective in reducing such growths, but that those containing TBM and HCM did not retard growth of the bacterial populations.

Material removed from tanks, pans, and pails, to which hexadecanol formulations had been applied, was smeared on hexadecanol agar plates and incubated at 35° C. The bacteria isolated were highly motile, gram-negative, nonsporulating rods. Biochemical and infrared spectrophotometric characteristics of four of those isolated indicated two of them were of the genus Pseudomonas, and two were of genus Flavobacterium.

Table 25. --Effect of Additives on Evaporation Control by Hexadecanol Film in Indoor Study at 24°-25° C.

Location	Duration of test days	Avg.evap. loss in control Ml/day	Total percent reductions in evaporation loss for each individual experiment										
			HD^x	HD on chlor.H_2O	HD + TBM#	HD + TCM#	HD + HCM#	HD + PCP#	HD + BCP#	HD + TCC#	HD + Bithionol#	HD + DCT#	CA + I_2
I	2	345;425	19;23	33;37	17;20	15;17	12;15	-	16;19	-	17;19	-	-
	3	365;380; 410	10;16; 18	34;38; 38	18;26; 26	5;10; 17	12;20; 23	19;22; 22	18;20; 21	6;11	11;16;19	7;12; 21	6*;7**
	4	310;335; 410;420	6;6; 12;13	34;34	10;16; 16;18	14;14; 15;16	13;14; 14;17	12;12 15	17;17; 17	5;5;11	5;13;13; 15	7;13; 13;15	8*;8**
	5	350;370	7;9	34;35	12;18	8;10	12;14	10;18	10;12	2;7	8;10	7;7	7*;8**
II	2	260;280	15;17	-	14	11	-	15	12	-	11	7	-
	3	200;265	8;11	-	16	9	13	-	13	6	5	-	-
	4	265	11	-	-	-	-	9	-	-	0	5	-
	5	210;270	8;10	-	13;19	-	13	-	9	-	11	-	11**
III	2	175;175	13;17	-	8;13	7;9	10	10;14	10;12	-	6;6	6;11	0*;2**
	3	210	10	-	15	13	4	15	13	-	5	5	-
	4	120	9	22	8	3	-	11	12	0	3	4	4**
	5	100;125; 200	5;7; 10	35;38	11;13; 16	7;12; 14	12;12; 13	12;12; 12	7;10; 11	0;0;5	2;9;12	0;3;5	2*;2*; 10**

Formulation contained 15% additive
HD^x Hexadecanol
* Formulation contained 7.5% I_2
** Formulation contained 2.5% I_2

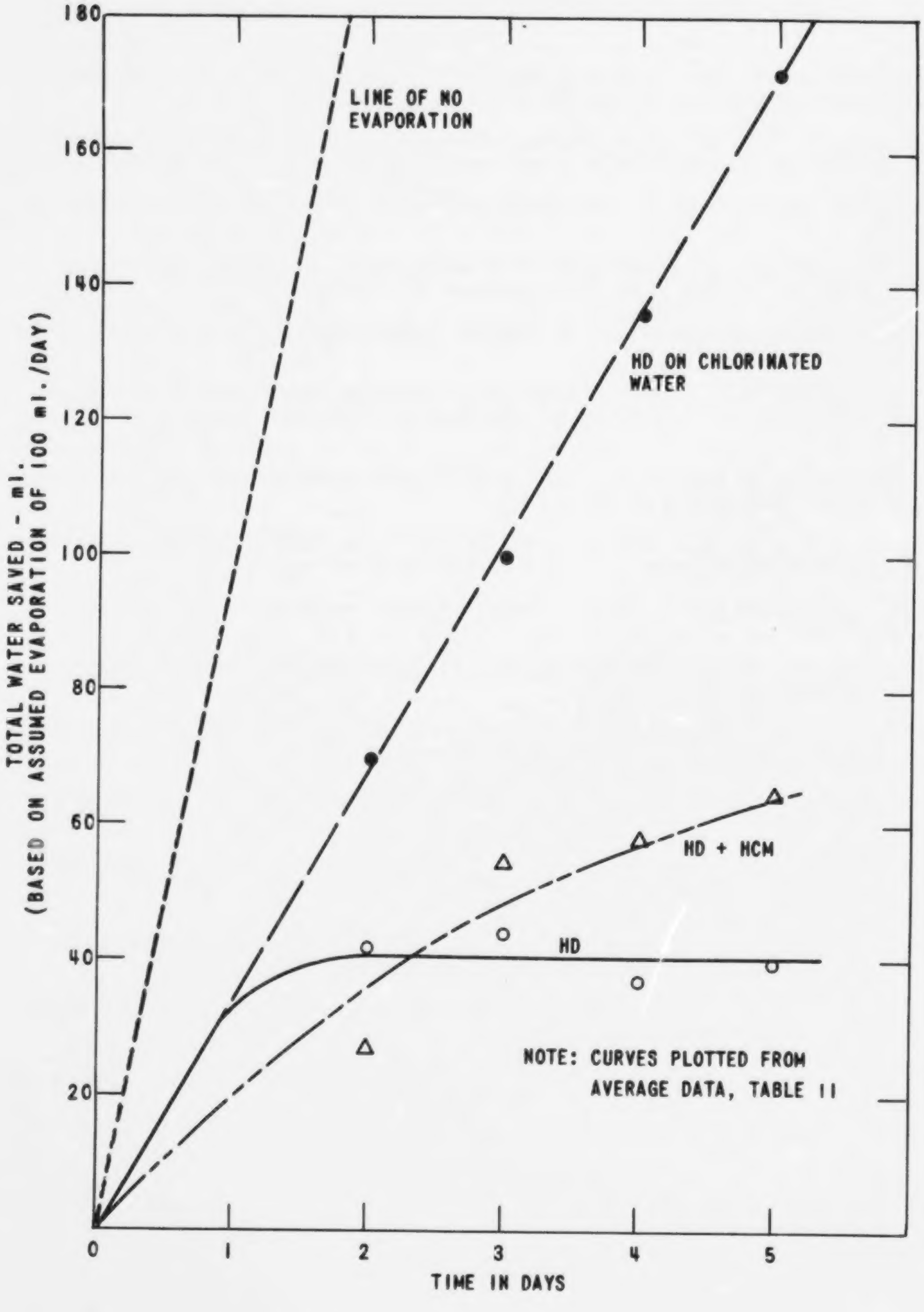

Figure 17. --Water Saving Through Single Treatment by Various Hexadecanol Formulations.

EXPLANATIONS* OF PHOTOMICROGRAPHS IN FIGURE 18

1. Material removed from surface of water of an untreated control tank in Location I after standing 24 hours. Notice the dust particles. X120.

2. Material removed from water surface 24 hours after the application of hexadecanol in Location II. Notice the hexadecanol crystals free from bacterial growth. X120.

3. The same control as in "1" after standing 48 hours. Notice the bacterial clumps. X120.

4. Material from the same tank as in "2" 48 hours after application of hexadecanol. Notice the development of bacterial growth on the hexadecanol crystal. X120.

5. The same preparation as in "4" at a higher magnification. Notice the bacillary shape of the bacteria. X240.

6. Material from water surface 72 hours after application of hexadecanol with 15 percent TBM in Location I. Notice the relatively fewer bacteria than those in "4." X120.

7. Material from the same control tank as in "1" after standing 72 hours. Notice the increase in bacterial population. X120.

8. Material from the same tank as in "4," 72 hours after application of hexadecanol. Notice the increased bacterial growth around the hexadecanol crystal. X120.

9. Same material as in "8," X240. Notice the greater variation in size of the bacilli than in "5."

10. Material from the same control tank as in "1" after standing 96 hours. Notice the rich bacterial population. X120.

11. Material from the same tank as in "2" 96 hours after the application of hexadecanol. Notice the dense bacterial growth around the hexadecanol crystal. X120.

12. Same preparation in "11," X240. Suggesting bacterial of the same morphological group.

13. Material from water surface 96 hours after application of hexadecanol and 15 percent TBM in Location I. Notice the slightly less bacterial growth than in "11." X120.

14. Material from water surface 96 hours after application of hexadecanol and 15 percent HCM in Location I. Distinctly fewer bacteria than in "11." X120.

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*The differences in bacterial growth noted above did not exclude variations due to differences in distribution of bacteria.

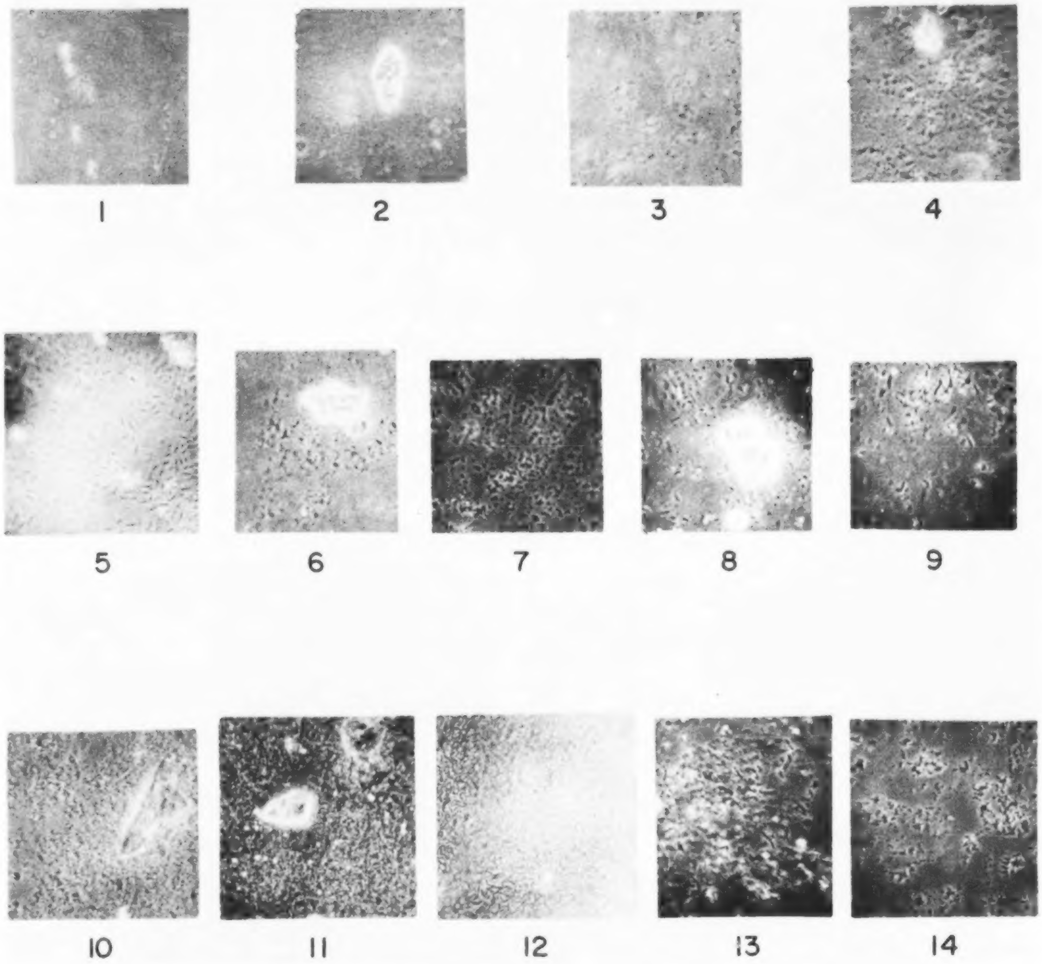
1
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Figure 18. --Bacteria in Surface of Water With and Without Hexadecanol Film.

Table 26. --Effect of Additives* on Evaporation Control by Hexadecanol Film in Outdoor Study.

Additive*	Duration of test in days	Prevailing water temp. °C	Avg. evap. loss in control ml/day	Total percent saving in evaporation loss over control	
				HD alone	HD + additive
Bithionol	2	28-31	520	18	7
TCM	2	26-30	320	14	12
BCP	3	26-30	?	11	14
I_2(2.5%)	3	26-28	120**	10	19
TBM	4	26-30	380	8	5
PCP	4	26-29	?	11	16
I_2(7.5%)	4	26-30	280	9	12
DCT	4	26-30	?	4	2
HCM	5	26-30	100**	10	9

* 15% unless specified otherwise.

? Water taken out in order to bring it to original level.

** Very high humidity encountered during these observation periods.

Five pails were filled with distilled water to which had been added 3 mg/l NH_4NO_3 and 1 mg/l Na_2HPO_4. A suspension of washed cells of one Pseudomonas sp. and one Flavobacterium sp. was added to each of four pails. Two of these were treated with 5 mg/ft^2 hexadecanol powder. Samples were taken from each pail and examined bacteriologically.

Results, which are shown in Figure 19, indicate a 10-fold increase in the Pseudomonas and Flavobacterium population in waters treated with hexadecanol, but only a 2-fold increase in the inoculated but untreated waters for the 7-day period. This shows that the presence of hexadecanol promotes rapid growth of these species of bacteria.

Studies were also made of the variation of film pressure with time, also the required compression to develop a film pressure of 40.4 dynes cm^{-1}, using a water contaminated with sewage and one inoculated with Pseudomonas and Flavobacterium. The results, which are shown in Table 27, indicate the monomolecular film breaks down more rapidly in the water seeded with Pseudomonas and Flavobacterium.

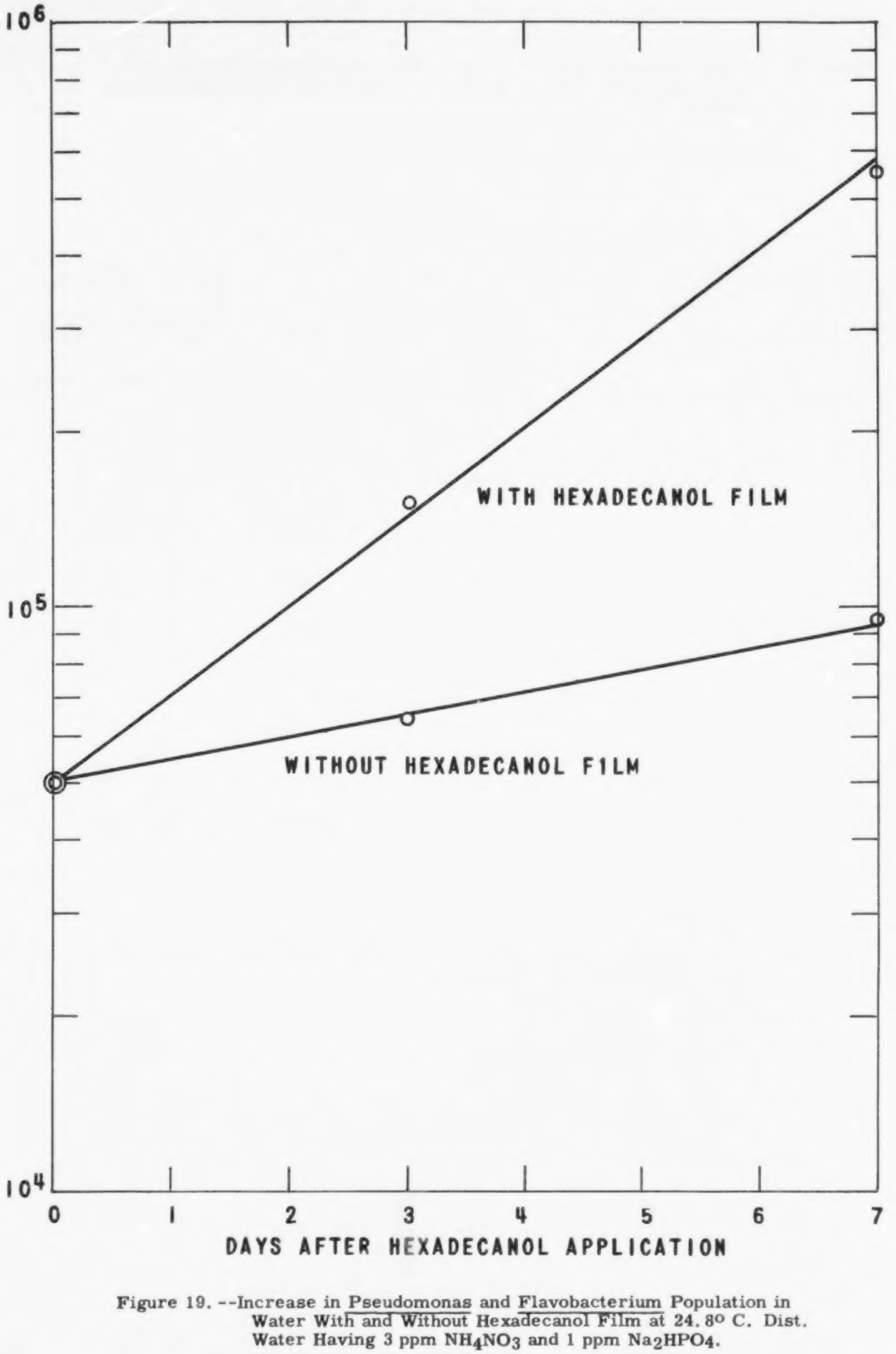

Figure 19. --Increase in Pseudomonas and Flavobacterium Population in Water With and Without Hexadecanol Film at 24.8° C. Dist. Water Having 3 ppm NH_4NO_3 and 1 ppm Na_2HPO_4.

Table 27. --Maintenance of Film Pressure of Hexadecanol on Water Containing Bacteria Grown on Hexadecanol Agar and on Sewage-contaminated Water.

No. hours after application of hexadecanol*	Film pressure (dynes cm^{-1})		(%)Area compressed in order to bring film pressure to 40.4 dynes cm^{-1}	
	On water having pseud and flavo	On sewage contaminated water	On water having pseud and flavo	On sewage contaminated water
2	40.4	40.4	None	None
6	40.4	40.4	None	None
22	40.4	40.4	None	None
30	40.4	40.4	None	None
46**	36.9	40.0	0.87	0.25
50**	30.5	40.0	1.45	0.25
54**	18.0	39.2	2.52	0.33
70***	Zero	15.0	31.10	2.40
78	Zero	Zero	31.00	32.00

*0.4 lb $acre^{-1}$

**Some dust patches were noticed on water surfaces which may have influenced the film pressure and compressibility.

***Dust patches more apparent.

Pseud - Pseudomonas
Flavo - Flavobacterium

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REVIEW OF LAKE HEFNER RESULTS

By Grady F. Mathews

State Department of Health
State of Oklahoma

REVIEW OF LAKE HEFNER RESULTS

A review of the study data of Lake Hefner investigation resulted in the following observations on the public health aspects of the evaporation reduction work:

1. There were no apparent toxic effects resulting from the application of hexadecanol.

2. There were no undesirable effects on the treatment processes of the lake water.

3. There was no interference with the normal recreational uses of the lake.

4. There was a large increase in the bacterial content of the lake water during the period of hexadecanol treatment, which after careful consideration, was deemed to be not significant.

These observations support the conclusion of this department that no deleterious effects resulted from the addition of hexadecanol to the Lake Hefner water supply.

LAKE HEFNER TESTS

EFFECTS OF HEXADECANOL ON WILDLIFE

By Vernon A. Perry

U. S. Department of the Interior
Bureau of Sport Fisheries and Wildlife

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EFFECTS OF HEXADECANOL ON WILDLIFE

The bird life on the lake, July 21-24, consisted of mallard ducks (three adults and four young) and eight heron (snowy egret). In addition, gulls and other small diving birds were seen on and around the lake shores. Because of the limited number of birds on the lake, the taking of samples was not practical. However, a close watch was kept on the birds observed, but no ill effects from or aversion to the alcohol was noted. The ducks appeared to eat the long strings of alcohol which collected in the water grass around the edge of the reservoir. The ducks did not appear to be doing any unusual amount of preening, and no alcohol could be noticed clinging to the feathers.

There were many water snakes around the lake and in the water. No aversion to the alcohol was evidenced by them although they were observed crawling through it.

It was noted with interest that the numerous fish in the lake frequently came to the surface in that part of the lake which was covered by the alcohol film. These fish were also seen eating some large particles of alcohol which were floating on the surface. Very few fish were observed breaking the surface of the untreated portions of the lake.

Conclusion

Although long-term ill effects upon wildlife from hexadecanol films may be forthcoming, no acute toxicity of hexadecanol to wildlife was observed during the above-mentioned period.

LAKE HEFNER TESTS

ECONOMIC EVALUATION

By H. S. Riesbol and
H. R. McDonald

U. S. Department of the Interior
Bureau of Reclamation

ECONOMIC EVALUATION

It was recognized during the planning of the evaporation reduction investigations at Lake Hefner that an accounting of costs would be an important factor in the evaluation of the results. It was also recognized that because investigations on such a large reservoir were unprecedented and of an experimental nature, that costs probably would be greater than those of subsequent tests. The techniques of application and the type of equipment best suited for the work were unknown. Inasmuch as the equipment was to be used for only a short period of time, the most expedient means of procuring equipment was used. As experience has shown, this equipment was not as rugged as that required for the most efficient operation.

Meticulous records were maintained on costs of (1) hexadecanol applied, (2) gasoline, oil, and repairs for operation of boats, (3) salaries and wages of operators and laborers, (4) motor vehicle operation, (5) rental of barge, (6) equipment depreciation, and (7) miscellaneous expenses. Overhead costs, including administrative, were excluded as well as laboratory expenses not directly related to the tests on Lake Hefner.

Table 28. --Cost Account--Lake Hefner Evaporation Reduction Investigations, July, 1958.

Day	Hexadecanol		Motorized equipment#	Labor*	Miscellaneous expense	Total expense
	Applied pounds	Cost at $0.515 per pound	$	$	$	$
1	0	0	0	11.93	0	11.93
2	0	0	0	11.93	0	11.93
3	600	309.00	24.57	58.56	6.25	398.38
4	0	0	4.87	11.93		23.05
5	0	0	4.87	11.93		23.05
6	0	0	4.87	11.93		23.05
7	0	0	4.87	11.93		23.05
8	1,400	721.00	60.84	120.74		908.83
9	1,475	759.62	63.31	126.57		955.75
10	1,100	566.50	50.99	97.42		721.16
11	75	38.63	17.34	17.76		79.98
12	750	386.25	39.50	70.22		502.22
13	150	77.25	19.80	23.59		126.89
14	0	0	14.87	11.93		33.05
15	1,000	515.00	47.71	89.65		658.61
16	1,000	515.00	47.71	89.65		658.61
17	200	103.00	21.44	27.47		158.16
18	1,000	515.00	47.71	89.65		658.61
19	0	0	14.87	11.93		33.05
20	875	450.62	43.60	79.94		580.41
21	500	257.50	31.29	50.79		345.83
22	700	360.50	37.85	66.34		470.94
23	700	360.50	37.85	66.34		470.94
24	0	0	14.87	11.93		33.05
25	400	206.00	28.00	43.02		283.27
26	300	154.50	24.71	35.25		220.71
27	10	5.15	15.20	12.71		39.31
28	825	424.88	41.96	76.05		549.14
29	400	206.00	28.00	43.02		283.27
30	50	25.75	16.51	15.82		64.33
31	500	257.50	31.28	50.79	6.25	345.82
Total	14,010	7,215.15	841.26	1,458.72	181.25	9,696.38

* Total expenditures for these items are prorated over the test period in the same ratio as the quantity of hexadecanol applied.

# Includes cost of fuel, repairs, and depreciation.

Table 28 (Continued). --Cost Account--Lake Hefner Evaporation Reduction Investigations, August 1958.

Day	Hexadecanol		Motorized equipment#	Labor*	Miscellaneous expense	Total expense
	Applied pounds	Cost at $0.515 per pound	$	$	$	$
1	350	180.25	26.37	39.13	6.25	252.00
2	400	206.00	28.00	43.02		283.27
3	700	360.50	37.85	66.34		470.94
4	1,025	527.88	48.52	91.60		674.25
5	1,000	515.00	47.71	89.65		658.61
6	1,150	592.25	52.63	101.31		752.44
7	875	450.62	43.60	79.94		580.41
8	0	0	14.87	11.93		33.05
9	0	0	14.87	11.93		33.05
10	1,100	566.50	50.99	97.42		721.16
11	900	463.50	44.42	81.88		596.05
12	700	360.50	37.85	66.34		470.94
13	500	257.50	31.28	50.79		345.82
14	900	463.50	44.42	81.88		596.05
15	675	347.62	37.03	64.39		455.29
16	800	412.00	41.14	74.11		533.50
17	0	0	14.87	11.93		33.05
18	530	272.95	32.27	53.12		364.59
19	550	283.25	32.93	54.68		377.11
20	75	38.63	17.34	17.76		79.98
21	0	0	14.87	11.93		33.05
22	375	193.12	27.18	41.08		267.63
23	300	154.50	24.71	35.25		220.71
24	600	309.00	34.57	58.56		408.38
25	675	347.62	37.03	64.39		455.29
26	500	257.50	31.28	50.79		345.82
27	850	437.75	42.78	77.99		564.77
28	950	489.25	46.07	85.77		627.34
29	275	141.63	23.90	33.30		205.08
30	75	38.62	17.34	17.76		79.97
31	825	424.88	41.96	76.05	6.25	549.14
Total	17,655	9,092.32	1,040.65	1,742.02	193.75	12,068.74

* Total expenditures for these items are prorated over the test period in the same ratio as the quantity of hexadecanol applied.

# Includes cost of fuel, repairs, and depreciation.

Table 28 (Continued). --Cost Account--Lake Hefner Evaporation Reduction Investigations, September 1958 and October 1, 1958.

Day	Hexadecanol		Motorized equipment#	Labor*	Miscellaneous expense	Total expense
	Applied pounds	Cost at $0.515 per pound	$	$	$	$
1	125	64.38	18.97	21.65	6.25	111.25
2	150	77.25	19.80	23.59		126.89
3	0	0	14.87	11.93		33.05
4	0	0	14.87	11.93		33.05
5	900	463.50	44.42	81.88		596.05
6	900	463.50	44.42	81.88		596.05
7	1,000	515.00	47.71	89.65		658.61
8	1,275	656.62	56.74	111.03		830.64
9	500	257.50	31.26	50.79		345.80
10	300	154.50	24.71	35.25		220.71
11	0	0	14.87	11.93		33.05
12						
13						
14						
15						
16						
17	0	0	14.87	11.93		33.05
18	1,200	618.00	54.27	105.20		783.72
19	0	0	14.87	11.93		33.05
20	200	103.00	21.44	27.47		158.16
21	0	0	14.87	11.93		33.05
22						
23						
24						
25						
26						
27	0	0	14.87	11.93		33.05
28	825	424.88	41.96	76.05		549.14
29	0	0	14.87	11.93		33.05
30	0	0	14.87	11.93		33.05
October 1	1,000	515.00	47.71	89.65	6.25	658.61
Total	8,375	4,313.13	735.94	1,020.78	193.75	6,263.60

* Total expenditures for these items are prorated over the test period in the same ratio as the quantity of hexadecanol applied.

# Includes cost of fuel, repairs, and depreciation.

Table 28 shows total daily cost of the entire field operation. Labor costs, with the exception of the salary of a subprofessional employee in charge of the field crew, were prorated in proportion to the total amount of hexadecanol applied to the lake. The salary of the subprofessional employee was included on a uniform daily basis during the entire period of the tests. Likewise, the cost of equipment operation was prorated on the basis of the quantity of hexadecanol applied. Equipment depreciation, rental of barge, and miscellaneous expenditures were included as a uniform daily expense. Thus, the costs accruing when no hexadecanol was applied due to unfavorable weather conditions, equipment outage, etc., were included. Table 29 presents costs incurred and the corresponding reduction in evaporation observed by the U. S. Geological Survey for seven periods during the tests. It is noted that costs per acre-foot of water saved ranged from about $58 to $86 with an average for the entire period July 7, to October 1, 1958, of $61.21. This compares with the value of raw water in Lake Hefner of about $60 per acre-foot, as reported by the city of Oklahoma City.

It will be noted from Table 28 that costs of hexadecanol were 73.5 percent of the total field costs, and therefore any significant reduction of material costs would have an important effect on the reduction of overall costs of the field operation. Based on discussions with manufacturers' representatives, it is anticipated that material costs may be reduced as much as 50 percent of present costs. This reduction is expected to develop as a result of several factors. First, an expanded market would permit use of plant capacity now idle; second, the development of synthetic materials has indicated substantial savings as compared to the use of the natural product; third, the requirement for hexadecanol in finely powdered form necessitates special processing by the manufacturer, which result in increased costs. Improved techniques, both in the manufacture and field application of hexadecanol could be expected to further reduce these costs. However, it has not been demonstrated that synthetic materials are superior or equivalent to the natural products in evaporation reduction potential.

Recent investigations have indicated that certain other substances have evaporation reduction characteristics superior to hexadecanol at the water temperatures experienced at Lake Hefner. Increased efficiency of the monolayer would increase the evaporation savings and thereby effect a lower unit cost.

Table 29. --Costs and Evaporation Reduction.

Period 1958	Total cost in dollars	Evaporation reduction (acre-feet)	Cost in dollars per acre-foot
July 15 through July 25	$ 4,351.48	69	$63.06
July 27 through August 7	4,953.79	85	58.28
August 10 through August 16	3,718.81	46	80.84
August 10 through August 19	4,493.56	54	83.21
August 23 through August 31	3,456.49	40	86.41
September 5 through September 12	3,313.98	42	78.90
July 7 through October 1	27,542.41	450	61.21

LAKE HEFNER TESTS

APPENDICES

APPENDIX I

Preliminary Evaporation Reduction Studies--
Lake Hefner, Oklahoma City, Oklahoma

WATER QUALITY STUDIES WITH HEXADECANOL

Kids Lake, Oklahoma City, Oklahoma

Report of Committee of Collaborators, April 15, 1957

WATER QUALITY STUDIES WITH HEXADECANOL--KIDS LAKE, OKLAHOMA CITY

I INTRODUCTION

Monomolecular Layers for Evaporation Reduction

During the last 30 years, careful laboratory studies have shown that monomolecular layers of certain materials can substantially reduce the evaporation from a water surface. Many of these layers, under carefully controlled conditions, can reduce the evaporation to about one ten-thousandth of the normal value. Some of these layers have the necessary properties to be able to work reasonably well under outdoor conditions.

Hexadecanol (cetyl alcohol), a waxlike solid, appears to be one of the better materials for use outdoors. Therefore, it is considered to be one of the most promising materials for reducing evaporation from large reservoirs when used as a monomolecular layer.

Full Scale Studies

It is a far cry from the outdoor test pans, 4 feet in diameter, where hexadecanol gave a 64 percent evaporation reduction to a reservoir thousands of acres in surface area. Therefore, it is apparent that to fully evaluate this method of reducing reservoir evaporation, a full scale evaporation reduction program should be made on a large reservoir.

For such a full scale test to be significant, the results must be sufficiently accurate to afford a reasonable evaluation of the method. This means that the test must be conducted on a reservoir where the water budget can be accurately determined.

This in itself is a very difficult problem for most lakes and reservoirs, as many factors greatly affect the water budget but are almost impossible to take into account. For example, bank storage, which is the spongelike action of the reservoir bank that can absorb, store, and later release large quantities of water.

In 1950, an extensive study was made at Lake Hefner, Oklahoma City, Oklahoma, to evaluate various means of evaluating lake evaporation. Lake Hefner was chosen after an extensive search for a suitable reservoir was made. To qualify, the reservoir had to be reasonably large and have a water budget which could be accurately determined. Lake Hefner met these qualifications quite well. It was natural then that Lake Hefner should be chosen as a site for full scale tests of the ability of a monomolecular layer of hexadecanol to reduce reservoir evaporation.

However, Lake Hefner is a part of the domestic water supply for Oklahoma City. Any treatment should not cause a toxic condition or result in a deterioration of the water quality.

Full clearance was obtained from the standpoint of toxicity to humans for the use of hexadecanol for such tests from the Food and Drug Administration, Department of Health, Education, and Welfare.

However, the effect upon the water quality could not be predicted with absolute certainty. Therefore, a steering committee was formed for the proposed full scale tests on Lake Hefner with hexadecanol.

On April 6, 1956, the committee met and discussed the proposed tests at Lake Hefner. At this time, it was decided the Lake Hefner program should be conducted in two phases. The first would be a study of the effect of a treatment on the water quality and the second would be the full scale evaporation reduction studies at Lake Hefner.

Lake Hefner Committee

The committee established for collaboration in the Kids Lake investigation and for future investigations at Lake Hefner is composed as follows:

Mr. L. N. McClellan (Program Coordinator)
Assistant Commissioner and Chief Engineer
Bureau of Reclamation
Denver 25, Colorado

Mr. Morrison B. Cunningham
Director of Public Works
City of Oklahoma City
Oklahoma City, Oklahoma

Dr. J. K. G. Silvey, Chairman
Science Division
North Texas State College
Denton, Texas

Mr. Bernard B. Berger, Chief
Water Supply and Water Pollution
Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

Mr. E. C. Warkentin, Regional Engineer
U. S. Public Health Service
Dallas, Texas

Mr. M. G. Barclay, Area Engineer
Bureau of Reclamation
Oklahoma City, Oklahoma

Mr. S. K. Jackson, District Engineer
U. S. Geological Survey
Oklahoma City, Oklahoma

Dr. Grady F. Mathews
Commissioner of Health
Oklahoma State Department of Health
Oklahoma City, Oklahoma

Object and Scope of the Kids Lake Tests

The first phase would consist of an application of a monomolecular layer of hexadecanol to Kids Lake and a subsequent evaluation of the water quality and factors which might affect the water quality. Kids Lake is a small lake (6 acres) located a few hundred feet from Lake Hefner. It is a former arm of Lake Hefner and was formed by a dike cutting off the arm.

The primary object of the Kids Lake test was to determine if the full scale tests on Lake Hefner would result in the deterioration of the water quality. This was to be evaluated by determining the quality of the water in Kids Lake and an untreated arm of Lake Hefner during tests. Also, observations were to be made on various biological and limnological elements of the lake which might affect the water quality.

It was not intended that the study be used as preliminary evaporation reduction test, as significant results could not be obtained because of its uncertain water budget. Also, it was not intended that the scope of the tests would include a thorough evaluation of the effects of a treatment upon the biological regime of a reservoir. However, many valuable observations in this field were made. Also, it was not part of the program to evaluate comparative methods of film application, maintenance and detection, but many valuable observations were made in this direction as well.

II COMMITTEE'S FINDINGS AND CONCLUSIONS

Water Quality

It is concluded that insofar as criteria of water quality, including taste, odor, color, toxicity, and other chemical qualities are concerned, nothing has been determined from this study to preclude further consideration of Lake Hefner for large scale evaporation reduction investigations with hexadecanol.

Effects on Biological and Limnological Factors

Temperature Readings

Although temperature measurements were not continuous and not always made under ideal conditions, it is considered that temperature measurements were adequate to determine that temperature changes were not great enough to have any real limnological importance.

Dissolved Oxygen

These data were based on concentration of dissolved oxygen in two different lakes and were not interpreted in terms of the percentage saturation factor. There was only a 2 percent of saturation variation in the oxygen content between the two lakes. It is concluded that, from the data available, hexadecanol does not greatly reduce the dissolved oxygen even in the surface meter of lake water.

Dissolved Inorganic Compounds

It is considered that the amount of change in concentration of inorganic constituents and of water lost by evaporation are not amenable to evaluation on the basis of the data. Furthermore, evaluation of evaporation was not originally intended in setting up the study.

Plankton Populations in Kids Lake

From the plankton studies, using Lake Hefner as a control, no observations made indicate a deleterious effect by hexadecanol.

Bottom Fauna

These data show that the hexadecanol did not affect this part of the lake biota which is, in our opinion, an important observation since the bottom fauna comprise an important segment of the fish food organisms. The emergence and reproduction of insections, including May flies, were not impaired.

Fisheries

As far as observations could be made, hexadecanol had no harmful effects on the fish present or on the ability of anglers to catch fish. On the basis of observations made during the period of study, there was no apparent effect on fish as based on the K factor measurements. It was suggested, however, that in the event of a large scale evaporation program, such as might be carried out on Lake Hefner, that observation on fish life be made during a treatment over a long period of time.

Sessile Algae

Although blue-green algae increased in greater quantities than green, it is likely that environmental changes, due to concentrated nutrients, were responsible for increased population of sessile algae rather than due to the treatment with hexadecanol.

Bacteria

With regard to *Pseudomonas* sp. and *Alcaligenes* sp., the number in Lake Hefner did not increase perceptibly during the study. In Kids Lake the *Pseudomonas* increased from 3 to 60 organisms per milliliter and *Alcaligenes* from 7 to 30 per milliliter. The increase in Kids Lake is not significant insofar as water quality is concerned, but it does indicate that treatment with hexadecanol might result in a more favorable environment for these bacteria. A pulse treatment should most likely result in a nearly normal bacterial flora. Insofar as the lake biology is concerned, an increase in bacteria would be advantageous since it would improve the lake fertility. However, an excessive increase in biological activity might produce undesirable taste and odor. It is concluded that the increase in *Pseudomonas* and *Alcaligenes* at Kids Lake is not adverse insofar as water quality of Kids Lake is concerned.

Film Application Maintenance and Detection

Improved methods of film application, maintenance and detection should be developed, as the methods used for the Kids Lake tests are judged inadequate and impractical for the large scale investigation.

III FILM APPLICATION, MAINTENANCE, AND DETECTION

Film Application and Maintenance

Initial Treatment

The initial treatment of Kids Lake was made between 10 and 11 a.m. on July 7, 1956. The lake was divided into approximate thirds, a boat was assigned each portion, and the hexadecanol broadcast upon the water. The hexadecanol was a mixture of 23-1/2 pounds of flake material and 23-1/2 pounds of granular material. This is at the rate of about 8 pounds per acre. The composition and certain properties of the hexadecanol are as follows:

Tetradecanol	1.1 percent
Hexadecanol	91.6 percent
Octadecanol	7.3 percent
Unsaturated	1.0 percent
Melting point	52° C. ± 1° C.

A slight breeze was blowing at the time of the application, and a few minutes after the material was first applied a definite quieting of the waves was noticed. After the application was completed, much of the material had blown to the leeward shore. Close examination revealed that the crystals and the granules of hexadecanol, as well as the monomolecular layer, apparently were being transported as a unit with the water surface. A definite and observable thickening of the film was observed on the leeward shore and on the windward side of large stationary objects in the lake. A test with hexadecanol mixed with talc revealed that the lake was covered with a monomolecular layer of reasonably high compression. The fish in Kids Lake were interested in the pieces of hexadecanol and at times appeared to eat them.

After the first week, most of the solid material was deposited upon the shoreline by the wind. In this location the hexadecanol was unable to effectively produce a film. Consequently, a few days after the initial treatment, tests available at that time for the presence of the film failed to give a clear indication of the film presence.

Subsequent Applications

Attempts were made to provide a continuous supply of material through coarse cloth bags. These efforts were not successful because of the clogging of the openings.

On July 14, 1956, seven cylindrical rafts containing the hexadecanol were installed. These rafts were constructed with 14-mesh brass wire screen. The rafts were made by making a tube 18 inches long and 3 inches in diameter with the screen. Wooden plugs were inserted in the end. Tests 48 hours later indicated that the rafts were producing a fair to good film.

By the end of July the weather had gotten so warm that the sun was heating the rafts above the melting point of the hexadecanol. Upon melting, the liquid hexadecanol would pass through the openings in the wire screen and out on the open water surface. This resulted in excessive consumption of the hexadecanol. To prevent this loss, three rafts of a different design were constructed and installed.

These rafts were made with a cover and bottom of 3/4-inch plywood and 4-inch corner posts. The rafts were 24 by 24 by 10 inches. The sides were covered with 14-mesh wire screen and the top covered with aluminum foil to reflect the sun's rays. It was felt that for the remainder of the tests these rafts continued to maintain a reasonable film for most of the time.

During the period of observations, there was no outflow from Kids Lake and only a very little inflow, from rainfall. Consequently, any material applied to the lake remained on the lake, or was deposited upon the shoreline.

Film Detection

The detection of the presence of the film was one of the more difficult problems of this study. The method used was the so called talc test. Talc and powdered hexadecanol were mixed in about even proportions. When applied to a clean water surface, the hexadecanol lowers the surface tension at the point of application. As a result, the mixture rapidly spreads outward. With a surface covered with a fully established monomolecular layer of hexadecanol, this effect is completely absent.

However, when used in the field, this method does not perform nearly as well as in the laboratory. Existing biological films, wind, and local surface currents all tend to cloud the results. It was felt that although the talc test was not a positive test, at certain times was helpful in determining the presence of the film.

IV WATER QUALITY, LAKE BIOLOGY, AND LIMNOLOGICAL ASPECTS

The primary aspect of the Kids Lake tests, water quality, and the closely associated lake biology and limnological aspects were under the supervision of Dr. Silvey. Not only were the tests at Kids Lake under his supervision, but he has made an intensive supplementary laboratory study at North Texas State College. The report on this phase of the tests, jointly submitted by J. K. G. Silvey, M. B. Cunningham, Frank S. Taylor, and Stuart Whitford, is as follows:

REPORT OF THE EFFECTS OF HEXADECANOL ON KIDS LAKE OKLAHOMA CITY, OKLAHOMA, JULY 7--SEPTEMBER 5, 1956

1. Temperature Readings. Temperature studies were done on one arm of Lake Hefner, having a depth of 3-1/2 meters, to be used as a comparative set of data in reporting the temperature changes measured in Kids Lake. Two sets of thermocouples were set up and installed, one in Kids Lake and one in the arm of Lake Hefner. Each set was comprised of 13 thermocouples with setting at zero and 2-1/2 centimeters deep and continuing at increasing intervals to 350 centimeters deep (Table I-1). A switchbox and potentiometer were used to make readings both on Lake Hefner and on Kids Lake. In addition, maximum-minimum thermometers were floated on the surface of Kids Lake, the arm of Lake Hefner, and at the intake tower on the north side of Lake Hefner. These thermometers did not survive the testing period so that data from those sources are incomplete. The thermocouple readings, except for various periods of difficulty, are complete enough to be used as evidence of thermal changes. Readings were taken for 3 days on Kids Lake and for 1 day on Lake Hefner before hexadecanol was applied.

Table I-1. --Evaporation Study Data.

	Kids Lake Time of Reading				Lake Hefner Time of Reading			
Depth Cm.	0600	1000	1400	1800	0600	1000	1400	1800
0	80.0	83.1	83.4	85.9	76.4	77.1	79.9	79.1
2.5	80.7	83.4	83.9	86.0	77.3	78.7	81.9	81.2
5	79.1	81.3	83.7	85.1	77.3	78.8	81.3	81.2
7.5	79.1	81.3	83.7	84.7	77.4	78.0	81.0	81.3
10	79.4	81.6	82.1	83.4	76.9	77.9	81.0	81.6
15	79.5	81.7	82.6	83.3	76.8	77.7	81.0	81.3
25	79.5	81.7	82.4	83.3	76.4	77.7	81.0	80.6
50	79.2	81.5	81.1	83.3	76.4	77.4	80.4	80.7
100	79.3	81.5	81.2	83.3	76.4	77.4	80.0	80.3
150	77.1	81.0	80.1	81.0	76.4	77.4	79.0	78.8
200	77.5	81.3	78.5	80.3	76.5	77.2	78.4	78.4
250	77.0	78.4	77.7	77.1	76.4	77.0	77.9	76.9
300	76.0	78.0	77.5	76.4	76.4	75.9	75.3	76.0
350	75.2	76.7	75.3	75.3	75.3	75.7	75.3	78.4
D. O. 1 meter	6.2	7.1	8.0	8.4	8.0	8.2	8.2	8.8
2 meter	6.0	6.4	7.4	8.4	7.6	7.8	7.4	8.6
3 meter	5.8	5.6	5.8	7.0	6.6	7.6	7.0	8.0
PH 1 meter	8.3	8.3	8.3	8.4	8.6	8.6	8.6	8.6
2 meter	8.3	8.3	8.3	8.4	8.4	8.5	8.5	8.5
3 meter	8.2	8.2	8.2	8.3	8.3	8.5	8.5	8.5

	T. Alk.	P. Alk.	Chl.	Th.	T&O	T. Alk.	P. Alk.	Chl.	Th.	T&O
1 meter	120	0	14	148	1&1	146	6.0	96	174	1&1
2 meter	120	0	14	145		147	2.5		226	
3 meter	122	0	13	144		146	3.5		230	

From the beginning of this study the thermocouple readings from Kids and Lake Hefner were somewhat erratic. Consistent results could not be duplicated with the equipment used in the investigation. The thermocouples were recalibrated near the middle of July, and the readings obtained throughout the remainder of the investigation appeared regular and dependable. In order to correlate the data so that earlier readings would be in agreement with later results, certain liberties were taken with all thermal data secured before July 19. This involved the determination of mathematical means for all readings taken prior to July 19, and in another group, all data taken after that time. The intermediate and specific differences in vertical changes of temperature were figured on a mean basis, so that a differential could be established to equate the errors in earlier readings. When this method was applied to the data it was found that the thermal readings taken earlier in the investigation agreed in profile with those obtained after the equipment was improved. This explanation is included so that members of the committee may reconcile the accompanying tables with the thermal readings sent to them during the summer.

The thermal data collected from July 5 to 7 is shown in Table I-1. It is interesting to note that the mean temperatures for this period from the surface thermocouples on both lakes were slightly lower than the readings obtained at the 2.5-cm level. Since no readings were taken during the period of darkness we cannot state that a similar differential existed throughout the 24-hour period. The difference in surface- and 2.5-cm thermal readings was variable, depending somewhat on the time of day, wind velocity, and rainfall, but the persistence of lower readings appeared to be considerable. Reference is made to Table I-2 that shows the mean thermal reading from both lakes during the experimental period. One observes that Kids Lake had higher thermal readings on the surface than at any other thermocouple location, while Lake Hefner continued the earlier pattern of lower surface readings. Evidently, the hexadecanol monolayer on the surface of Kids Lake affected the thermal conditions due to the lack of normal evaporation, thereby creating higher readings. Possibly thermal recording equipment including thermocouples at the surface and 2.5 cm would be sufficient to show the presence of a monolayer on a small lake. Where larger bodies of water are used, more extensive thermocouple setting would be required because of the greater wave action.

Table I-2. --Evaporation Study Data.

	Kids Lake				Lake Hefner			
	Time of Reading				Time of Reading			
Depth Cm.	0600	1000	1400	1800	0600	1000	1400	1800
0	81.8	84.6	86.4	84.6	77.2	78.0	78.6	78.4
2.5	79.8	82.2	85.3	84.5	77.8	78.8	80.1	79.8
5	79.3	82.2	84.4	84.5	78.6	79.6	80.2	79.9
7.5	78.3	80.4	83.8	84.1	78.4	79.8	80.1	79.7
10	78.3	79.7	83.4	83.6	76.8	79.4	80.0	79.7
15	78.3	79.6	83.4	83.6	76.8	79.4	80.0	79.7
25	78.2	78.4	82.3	83.4	76.6	79.4	80.0	79.6
50	78.6	78.2	82.1	83.2	76.4	79.4	80.1	79.7
100	78.2	79.6	82.9	83.3	76.8	79.4	81.2	79.9
150	77.9	79.0	78.7	83.0	77.0	79.3	79.8	79.6
Top D.O.	7.0	7.0	7.3	7.4	7.3	7.3	7.6	7.8
Middle	6.9	6.8	7.0	7.1	7.2	7.2	7.2	7.6
Bottom	5.4	5.6	5.8	6.2	7.0	6.8	7.0	7.2
Top PH	8.6	8.7	8.7	8.7	8.8	8.8	8.8	8.8
Middle	8.5	8.6	8.7	8.7	8.7	8.7	8.8	8.8
Bottom	8.5	8.5	8.6	8.6	8.7	8.7	8.7	8.8

	T. Alk.	P. Alk.	Chl.	Th.	T&O	T. Alk.	P. Alk.	Chl.	Th.	T&O
Top	125	5	13	144	2&1	127	8	83	208	2&2
Middle	125	5	13	144		127	8	83	206	
Bottom	126	4	14	143		128	7	83	206	

Table I-3 shows a comparison of the thermal data taken before and after the addition of hexadecanol to the surface of Kids Lake. These data are included in this fashion so that rapid reference may be made for comparison. The only observation that implied limnological importance was the presence of the warmest water on the surface of the lake. Possibly this physical phenomenon might induce more rapid thermal stratification in a reservoir, resulting in more extensive formation of a hypolimnion. From a practical standpoint this would be undesirable since it would result in water of a lower quality for the consumer and more expense to the city. In like manner, the biological productivity from a fisheries standpoint would be somewhat reduced. These comments are speculative, since we are not certain that an elevation of surface temperatures would result in more rapid formation of a thermocline since the warming effects might be more general than local in the body of water.

2. Dissolved Oxygen. Measurements were made on Kids Lake and the arm of Lake Hefner beginning on July 3 and continuing through the course of the study. Early readings prior to the time hexadecanol was added to Kids Lake show that the dissolved oxygen contents in Kids Lake were slightly lower than the quantity found in Lake Hefner (Table I-1). This probably could be attributed to the turbidity of the water, the lack of wind action, and the fact that Kids Lake is not attached to a large body of water that would be affected by varieties of wave action, convection currents, and seiches. After the hexadecanol was added on July 7 for a period of over a month, dissolved oxygen readings were made on both Kids Lake and Lake Hefner four times each day. The minimum readings occurred at 6 a.m., maximum readings at 6 p.m. (Table I-2, I-3). Observations obtained during the 60-day experimental period indicated that the dissolved oxygen was slightly lower in Kids Lake than it was in Lake Hefner. (Table I-2.) The differential between the two bodies of water was very similar to that observed before the time

hexadecanol was applied to Kids Lake. We might well conclude that so far as we can tell from the data, hexadecanol does not greatly reduce the dissolved oxygen even in the surface meter of lake water.

Table I-3. --Evaporation Study Data.

Kids Lake

Depth Cm.	July 5-7, 1956 Time of Reading				July 16-Aug. 30, 1956 Time of Reading			
	0600	1000	1400	1800	0600	1000	1400	1800
0	80.0	83.1	83.4	85.9	81.8	84.6	86.4	84.6
2.5	80.7	83.4	83.9	86.0	79.8	82.2	85.3	84.5
5	79.1	81.3	83.7	85.1	79.3	82.2	84.4	84.3
7.5	79.1	81.3	83.7	84.7	78.3	80.4	83.3	84.1
10	79.4	81.6	82.1	83.4	78.3	79.7	83.4	84.1
15	79.5	81.7	82.6	83.3	78.3	79.6	83.4	83.6
25	79.5	81.7	82.4	83.3	78.2	78.4	82.3	83.4
50	79.2	81.5	81.1	83.3	78.6	78.2	82.1	83.2
100	79.3	81.5	81.2	83.3	78.2	79.6	82.9	83.3
150	77.1	81.0	80.1	81.0	77.9	79.0	78.7	83.0
200	77.5	81.3	78.5	80.3				
250	77.0	78.4	77.7	77.1				
300	76.0	78.0	77.5	76.4				
350	75.2	76.7	75.3	75.3				

D.O.	1 meter	6.2	7.1	8.0	8.4	top	7.0	7.0	7.3	7.4
	2 meter	6.0	6.4	7.4	8.4	middle	6.9	6.8	7.0	7.1
	3 meter	5.8	5.6	5.8	7.0	bottom	5.4	5.6	5.8	6.2
pH	1 meter	8.3	8.3	8.3	8.4	top	8.6	8.7	8.7	8.7
	2 meter	8.3	8.3	8.3	8.4	middle	8.5	8.6	8.7	8.7
	3 meter	8.2	8.2	8.2	8.3	bottom	8.5	8.5	8.6	8.6

	T. Alk.	P. Alk.	Chl.	Th.	T&O		T. Alk.	P. Alk.	Chl.	Th.	T&O
1 meter	120	0	14	148	1&1	top	125	5	13	144	2&1
2 meter	120	0	14	145		middle	125	5	13	144	
3 meter	122	0	13	144		bottom	126	4	14	143	

3. Dissolved Inorganic Compounds. Specific analyses were run each day on Kids Lake and the Lake Hefner arm. The tests that were chosen as indices of inorganic content were total alkalinity, phenolphthalein alkalinity, chlorides, and total hardness, the latter being a measurement of calcium and magnesium as calcium carbonate. Since the inorganic concentrations in Lake Hefner and Kids Lake were not similar there is little to be gained by showing the relative quantity at the beginning and the end of the experimental period in these two reservoirs. Furthermore, 4 feet of water were added to Lake Hefner after the beginning of the experimental period so that mineral analyses from that reservoir would be of slight comparative value. Suppose we treat the data from mineral analyses in the same manner as the thermal data, that is, by taking the mean values early in the investigation and later after the hexadecanol was applied to the lakes (Table I-3). There was a slight average increase in total alkalinity in Kids Lake during the period of investigation. The average mean increase was 5 ppm while the maximum increase very near the end of the investigation was 19 ppm. The phenolphthalein alkalinity showed an average mean increase of 5 ppm with a maximum near the end of the period of 9 ppm. The chloride content of the water in Kids Lake remained very nearly constant. On a mean average basis there was no change, however, at the conclusion of the investigation several determinations showed a 2 ppm increase. The total hardness of the water in Kids Lake did not show any definite changes when compared on a mean average basis. The calcium and magnesium expressed as calcium carbonate remained constant throughout most of the experimental period. Near the termination of the investigation, however, the increase in total hardness amounted to about 21 ppm on at least three samples. When the quantities of calcium and magnesium were figured on a mean average basis rather than on maximum change there appeared to be little significant alteration in those two components.

It was not the intent of this study to evaluate evaporation control since the hydrology of the reservoir and its basin were not studied. We are aware of seepage from Kids Lake into Lake Hefner, although the quantities are unknown. It would appear that the data on mineral concentration are not conclusive, but are offered for comparative purposes.

4. **Plankton Populations in Kids Lake.** This is part of the investigation having to do with the effect of cetyl alcohol on the lake biota. We agree that long term studies are essential in order to evaluate the effect of hexadecanol on fish food organisms. The plankton studies concerned themselves with micro-organisms secured at intervals of 1 meter of depth, or from top to bottom in Kids Lake and in Lake Hefner. The method employed was the Sedgewick-Rafter concentration technique. Samples collected consisted of 500 ml of raw water concentrated to 5 ml. Counts were enumerated in terms of standard areal units as well as in terms of organisms per cc. First, a brief consideration might be given to the phytoplankton since they appeared to be more numerous both as to species and population. During the 60-day period there was little evidence of any deleterious effect on the phytoplankters per se. The species varieties remained about the same with some evidence of increase in the diatoms. However, in Kids Lake they showed a population pulse, beginning on July 18 and rising to a maximum by July 25, which amounted to approximately 300 standard areal units. (Figure I-1.) During the remainder of the experimental period there was a decrease in population to a low of 20 s. a. u. by August 29. Apparently the pulse or bloom in Kids Lake was a regional limnological expression since a similar phytoplankton bloom of less intensity was noted in Hefner only one week later. Since Kids Lake received run-off water from relatively rich organic sources it is likely that the fertility of this lake was greater than that of Lake Hefner. The zooplankton revealed a slightly different reaction (Figure I-1). In the early part of the study they were relatively numerous both in quality and quantity. By the first of September the population was very sparse. It should be stated that the same condition could be observed in Lake Hefner, and from our studies of reservoirs in the southwest we are inclined to think that the period from the last of August to the middle of September is usually attended by obvious reductions in zooplankters. From the plankton studies, using Lake Hefner as a control, no observations can be made that indicate deleterious effects by hexadecanol.

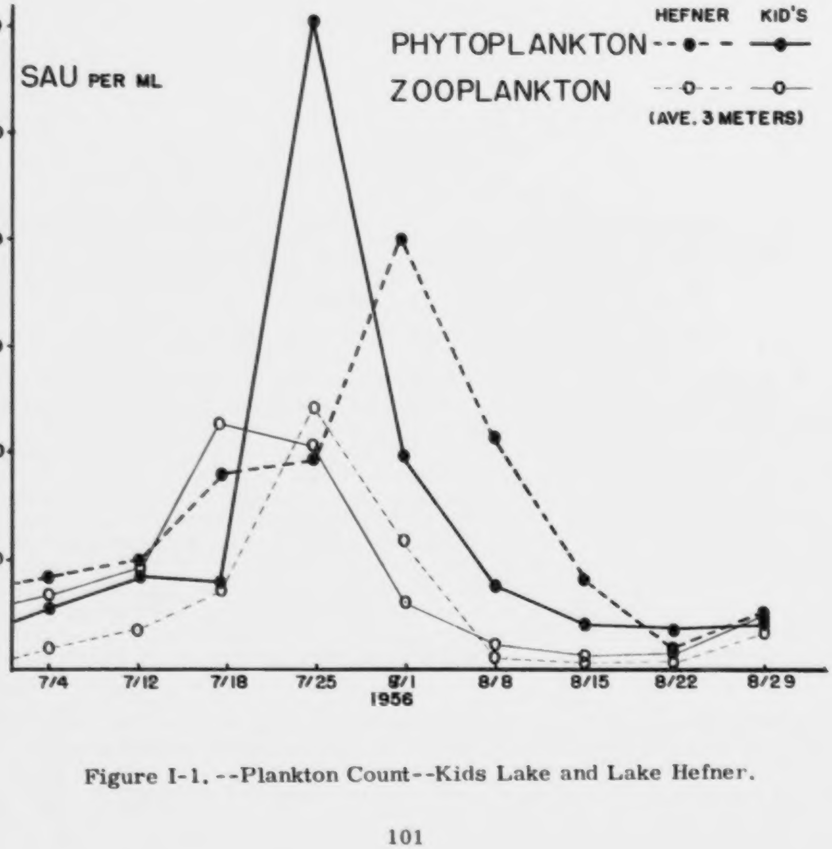

Figure I-1. --Plankton Count--Kids Lake and Lake Hefner.

5. Bottom Fauna. The bottom fauna were studied in both Lake Hefner and Kids Lake. A Petersen dredge was used to collect 3 square feet of bottom muck from each lake which was run through a No. 40 soil sieve. The organisms obtained were isolated, identified, and counted. Except for the period of around August 4, the bottom fauna in Kids Lake remained consistently high. At that period there was an emergence of May flies and Corethra which accounted for the reduction in bottom fauna organisms (Figure I-2). In a short period of time the naiads returned in high concentrations although they were earlier instars than those previously collected. These data show that the hexadecanol did not affect this part of the lake biota, which is, in our opinion, an important observation since the bottom fauna comprise an important segment of the fish food organisms. It further demonstrates that the monolayer does not interfere either with emergence of mature forms nor with the egg laying habits of the adults of the May flies or mosquitoes.

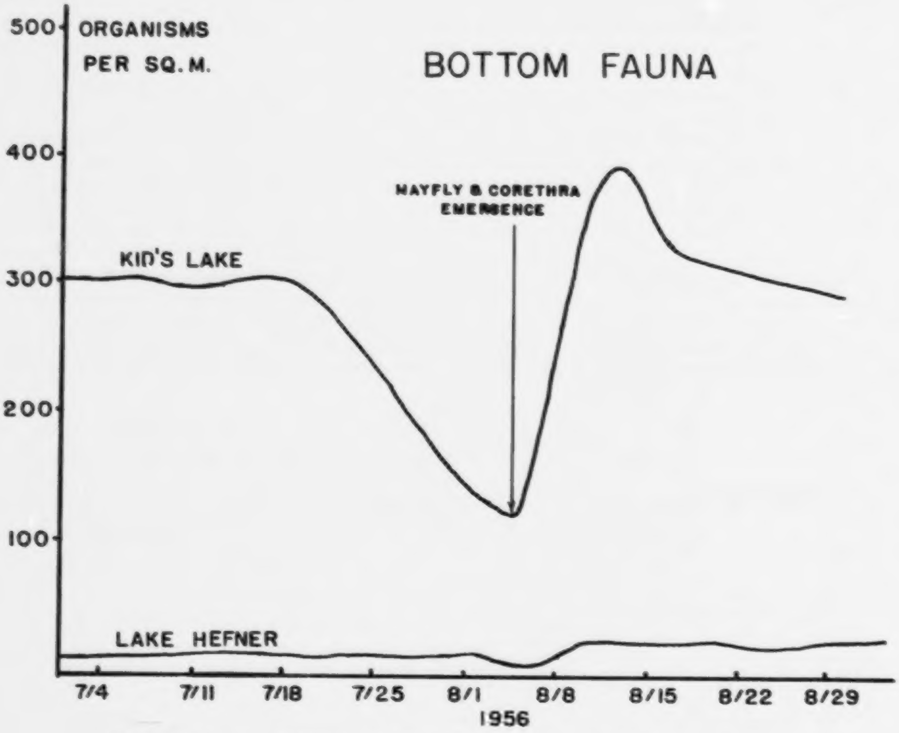

Figure I-2. --Bottom Fauna, Kids Lake and Lake Hefner.

6. Fisheries. Prior to the time hexadecanol was added to Kids Lake, a survey was made of the fish population by the use of gill nets. The predominant game species obtained in the survey was white crappie, average weight approximately 120 grams, K factor 0.86. Additional species were large-mouthed black bass, channel catfish, shad, and green sunfish. The shad composed the major fish population with an average weight of 160 grams and in excellent condition. The bass, catfish, and green sunfish were present in relatively small numbers. During the experimental period no fish were observed floating on the surface of the water. Children fishing in Kids Lake obtained specimens of crappie and a few bass throughout the course of the study. They appeared to have the same K factor or even a slight improvement over the condition that existed in the first week in July. No detailed survey was made at the conclusion of the study since specimens were obtained throughout the course of the study. As far as observations could be made, hexadecanol had no harmful effects on the fish present or on the ability of anglers to catch fish.

7. Sessile Algae. Observations on sessile algae during the first week of study on Kids Lake showed a marginal growth of filamentous green algae with a sparse population of sessile blue-greens. Throughout the course of the study the quantity of green algae consistently increased, indicating a condition favorable to their growth. By observation

alone, we would predict that the sessile green algae increased 300 percent. The sessile blue-greens also increased particularly in the northeast part of the lake. This particular growth was Oscillatoria, and the extent of its increase would be problematic since it was clinging to the bottom muck in many places and probably grew to depths beyond normal vision. It should be held in mind that the increase in sessile algae occurred concomitantly with loss in water level. We could infer that a more suitable environment was provided by greater amounts of shallow water and by the concentrations of nutrient substances. This, of course, is mere speculation. At least, observations indicated no deleterious effects from hexadecanol.

8. Bacteria. It was shown by F. J. Ludzack and M. B. Ettinger in their work at the Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, that there was a strong indication that cetyl alcohol was utilized by organisms contained in river water that had been seeded to produce a theoretical 30 to 60 percent biological oxygen demand. No statements were made by Messrs. Ludzack and Ettinger concerning the types of organisms that might be responsible for the reduction of alcohol.

Bacterial samples were collected both from Lake Hefner and from Kids Lake at intervals of once per week throughout the course of the study. One milliliter samples of water were plated on regular nutrient agar and the plates were counted in our laboratory with special identification of two groups of bacteria. We were interested in the effects on Pseudomonas sp. and Alcaligenes sp. To be certain, Proteus, Escherichia coli, Shigella, and other organisms were observed although we made no particular point of enumerating them.

In the beginning of the study on Lake Hefner, populations of Pseudomonas averaged 3 per milliliter, while Alcaligenes averaged 4. Near the termination of the study, the number of organisms in Lake Hefner had not increased perceptibly. In Kids Lake, the original counts of Pseudomonas were 3 per milliliter and of Alcaligenes were 7. Samples procured near the middle of August showed average Pseudomonas count of 60 organisms per milliliter, Alcaligenes 30 organisms per milliliter.

Field observations are probably pertinent at this time. According to Messrs. Mullens and Waldron, the two technicians who completed the work, the following observations in relation to hexadecanol have been accounted. Various techniques were attemped in order to obtain a persistent layer on the surface of the lake. Seven rafts were installed in July that proved only partially effective. On the 11th of August three new rafts were installed, each containing 14 pounds of cetyl alcohol provided with a cover so that the heat of the sun would not melt it. In observing the cetyl alcohol in the rafts, it was observed that the color on the surface changed from white to creamy with apparent losses of the compound that could not be attributed to wave action. These losses may have been due to the bacterial activity.

The increase in Kids Lake is not significant insofar as water quality is concerned, but it does indicate that treatment with hexadecanol might result in a more favorable environment for these bacteria. A pulse treatment should most likely result in a nearly normal bacterial flora. Insofar as the lake biology is concerned, an increase in bacteria would be advantageous since it would improve the lake fertility. However, an excessive increase in biological activity might produce undesirable taste and odor. It is concluded that the increase in Pseudomonas and Alcaligenes at Kids Lake is not adverse insofar as water quality of Kids Lake is concerned.

After the treatment with hexadecanol was terminated for a period of 2 weeks, additional samples of water from Kids Lake were plated out for a continuance of the bacteriological studies. We noted that in the brief period of time the population of Pseudomonas had decreased to two per milliliter while the Alcaligenes had also decreased in the same manner. This evidence seemed to indicate that the bacteria by utilizing the hexadecanol had increased during the experimental period and when this source of nutrition was removed, a decided decrease occurred. Possibly this evidence will be of some importance in later experimental work in the event of unusual bacterial populations in treated surface waters.

On September 18 we started some investigations on the destruction of hexadecanol by certain varieties of Pseudomonas and Alcaligenes isolated from Kids Lake and from Lake Hefner. These two genera were chosen for experimental purposes since they showed the greatest increase in population during the 60-day study of Kids Lake. Samples of water collected from Kids Lake were used as the liquid medium for the investigation. Half of the samples were autoclaved before the hexadecanol was added while the remaining culture flasks were made up with raw unsterile water. At the same time a number of flasks were prepared containing Frazier-Rupps mineral solution. Flakes of hexadecanol were added to each flask, varying from 1 to 100 ppm on a weight basis; the flasks were then seeded with Pseudonomas and Alcaligenes that had been isolated from both lakes. The flasks were permitted to incubate at room temperature for a period of 3 weeks at the end of which time counts were made from each group of cultures. Some of the varieties of the above genera did not grow, while others multiplied freely. No attempt was made to determine the varieties since several from each of the lakes produced high populations. The results from these first experiments indicated that the bacteria grew more freely in the raw unsterile water with higher concentrations of hexadecanol. In the sterilized water samples as in the Frazier-Rupps solution, containing 1 ppm hexadecanol the increase was about 100-fold. In the same solutions with 100 ppm hexadecanol the increase was about 1,000-fold. In the raw unsterile water with 1 ppm hexadecanol the increase was 500-fold, and with 100 ppm the increase was 10,000-fold. In each instance it would be proper to state that Pseudomonas increased in greater proportion than Alcaligenes.

The investigation has continued through the winter months and additional data have given us some indication of why the bacteria grow better in the unsterile water from Kids Lake. We have run raw water through millipore filters, then used it in cultures and obtained similar results in bacterial population increases as found in the raw unsterile water. This indicated that some dissolved materials must be present that contributed to the bacterial nutrition in addition to the hexadecanol. Rather detailed analyses revealed that both organic and inorganic nitrogen were present in the raw water, but were either lost or inactivated completely in the autoclaved samples. After we determined the quantities of nitrogen present, and made equivalent additions to Frazier-Rupps solution, we obtained approximately the same results in that medium as in raw unsterile water plus hexadecanol.

The degradation of hexadecanol appears quite evident from our laboratory findings. There are several points that must be investigated before detailed statements can be made. We should determine hexadecanol utilization in relation to time, temperature, quantity and bacterial population density. This will reveal the increase in organisms and show the quantities of hexadecanol that are continuously required to maintain a complete monolayer. Such information will be of economic value in that it should indicate percent of increase in cost of hexadecanol as a program continues. In addition, and possibly just as important, is the determination of the increase in organism as the fluid medium below the monolayer increases in depth. Most of our work has utilized regular laboratory flasks where minimum thicknesses of fluid could be obtained. We now propose to go to large glass columns having depths from 10 cm to 200 cm in gradients of 10 cms each. They will be constructed so that samples of fluid below the monolayer may be taken at centimeter levels if necessary and the bacterial populations determined. Possibly in this manner we may construct a curve to show density of bacterial populations at different levels below the hexadecanol. Such information could be of value in determining if it is practical to attempt evaporation control on water surfaces where impoundments are very shallow.

The degradation of hexadecanol by bacteria is not an encouraging fact from the standpoint of its future application for evaporation control. However, it appears that the degrading process may begin before the alcohol is applied to a water surface. We have found that flake and granular samples of hexadecanol vary in their bacterial flora as to quantity and types. Some samples contain dense populations of Pseudomonas when they are examined directly from the producer. Other samples contain Alcaligenes in almost pure cultures, while it is common to find both genera of bacteria growing profusely in the commercial preparation. Possibly considerable deterioration has occurred in the cetyl alcohol before it is applied on water. With these observations it might be reasonable to suspect that the bacteria native to water supplies are not of great importance, provided the contaminating varieties in the hexadecanol can reproduce in an aqueous medium.

9. Taste and Odor. One of the major intents of the investigation on our part was to determine the effect of hexadecanol on water quality. An important item in water

quality, particularly in the Southwest, is the presence of taste and odor producing compounds. Tastes and odors were run at intervals on Lake Hefner as well as on Kids Lake. Data were recorded in the reports prepared by Mr. Whitford that revealed the threshold odor numbers and the threshold taste numbers. An examination of these data indicated that Kids Lake did not demonstrate any threshold odors or threshold tastes that were in excess of those found in Lake Hefner. This observation, we feel, indicates that in the experiment on Kids Lake this particular feature of water quality was not appreciably altered.

10. General Comments.

(1) New techniques probably should be improvised that would result in the continuous formation of a monomolecular layer that would be more persistent. This would involve the study of "usable solvents" accompanied by complete information on bacterial degradation.

(2) A technique is needed to make more accurate determinations on the presence of the monomolecular layer, since the talc techniques were indeterminate. Possibly thermal recording equipment or "indicator oils" may be used to determine the presence of a film.

(3) Studies should be completed on larger lakes where accurate hydrology is available so that estimates of real evaporation control can be made without error.

(4) Hexadecanol, when applied as a solid or as a solution to the surface of the water, passed completely through a surface intake pilot grade water purification plant. It was observed in the laboratory of North Texas State College that the copper tubing did not remove the hexadecanol as the water passed through, nor was the filter in any way effective in removing hexadecanol.

11. General Conclusions by the Committee of Collaborators:

"It is concluded that insofar as criteria of water quality, including taste, odor, color, toxicity, and other chemical qualities are concerned, nothing has been determined from this study to preclude further consideration of Lake Hefner for large scale evaporation reduction investigations."

V ACKNOWLEDGMENTS

From time to time during the committee meetings and during the actual conduction of the tests, the committee members were represented by various persons from their respective staffs. Those who acted in this capacity are as follows:

For L. N. McClellan--W. T. Moran, H. S. Riesbol,
W. U. Garstka, R. C. Mielenz, L. O. Timblin,
and Q. L. Florey

For M. B. Cunningham--F. S. Taylor and S. Whitford

For B. B. Berger--A. Bartsch

For M. G. Barclay--M. Berger

For G. F. Mathews--L. Clark

In any cooperative program such as this, the close cooperation of many individuals is necessary for a successful test to be accomplished. The success of this program could not have been achieved without the enthusiastic efforts during the tests of:

Leroy Buettner, Hydrologist, Bureau of Reclamation,
Oklahoma City, Oklahoma

Stuart Whitford, Purification Superintendent, Lake Hefner Treatment Plant, City of Oklahoma City

Messrs. Waldron and Mullens, North Texas State College

APPENDIX II - A

DETECTION AND EVALUATION OF DEGREE OF COMPRESSION OF A MONOMOLECULAR LAYER

By L. O. Timblin, Jr.

DETECTION AND EVALUATION OF DEGREE OF COMPRESSION OF A MONOMOLECULAR LAYER

One of the problems recognized early in the investigation was that of determining the presence of the monolayer and its degree of compression. The first method devised to test for the film presence was the talc test. However, this test was difficult to interpret under field conditions, and further studies were made. The calibrated indicator oils resulted from this work.

Both the talc test and the indicator oils are dependent upon the film pressure of the monomolecular layer for their operation. The measurement of film pressure is also important, as the higher the film pressure of a hexadecanol monolayer, the greater the evaporation reduction. This is illustrated in Figure II-A-1, which is based upon data by Mansfield, and Rosano and LaMer, 27/, 28/.

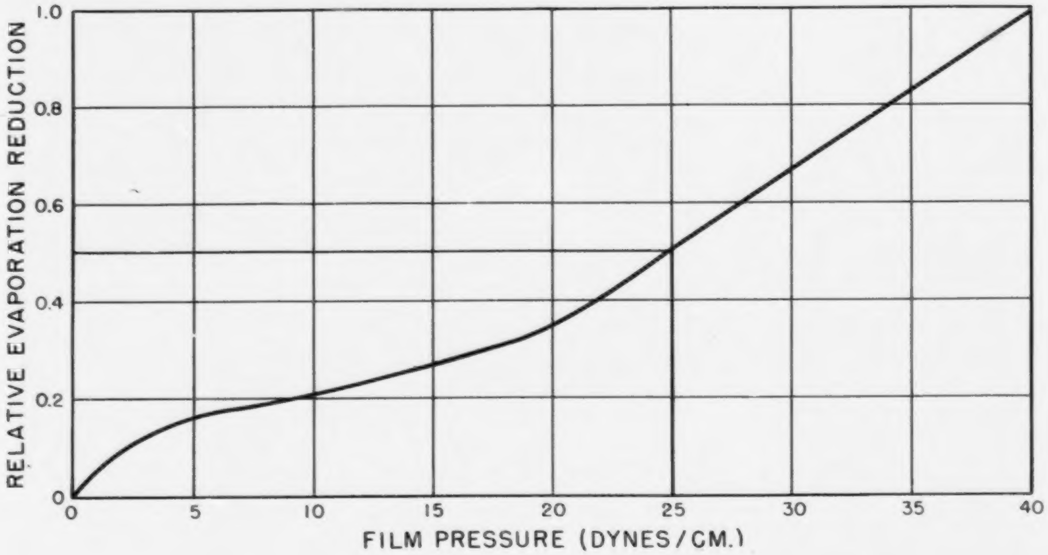

Figure II-A-1.--The Effect of Film Pressure on Evaporation Reduction for Hexadecanol.

The development and use of indicator oils, as described by Timblin, Moran and Garstka 29/ pages 846 and 847, was a condensation of Bureau of Reclamation Chemical Engineering Laboratory Report No. SI-13, which is reprinted at the end of this appendix.

Field tests conducted at Ralston Creek, Rattlesnake, and Carter Lake Reservoirs with the indicator oils demonstrated that the presence of even a slightly compressed monomolecular layer was visible as a smooth patch of water. Characteristic "slicks" with film pressures as low as 5 to 10 d/cm were observed. These slicks are produced by the elimination of small waves or ripples by the reduction of surface tension caused by the film.

However, on these mountain lakes, apparent slicks were often observed which were not produced by the film but simply because the wind was not blowing on that particular part of the lake surface. Through careful examination of the surface, by an experienced observer, apparent or no-film slicks and fully compressed film slicks could be differentiated. Because of the possible false indications of the presence of the film and in order to study film behavior, the indicator oils were used extensively during the 1957 field tests.

It was soon found that the visible quieting of ripples caused by the film could also be photographed from the shore. This is shown in Figures II-A-2 and II-A-3 taken at Ralston Creek Reservoir. The advantages of photographic aerial surveys were immediately apparent. The feasibility of this approach was clearly demonstrated in June 1958, at Carter Lake. The 3415th Technical Training Wing of Lowry Air Force Base, Denver, made two flights over Carter Lake photographing the film. A typical photograph obtained in the flights is shown in Figure II-A-4. It was learned in this work and later confirmed in similar aerial photo studies at Lake Hefner that the angle the picture is taken, the position of the sun, and cloud and haze conditions significantly influence the photograph and at times require special techniques, not yet completely worked out, to show the layers' location photographically.

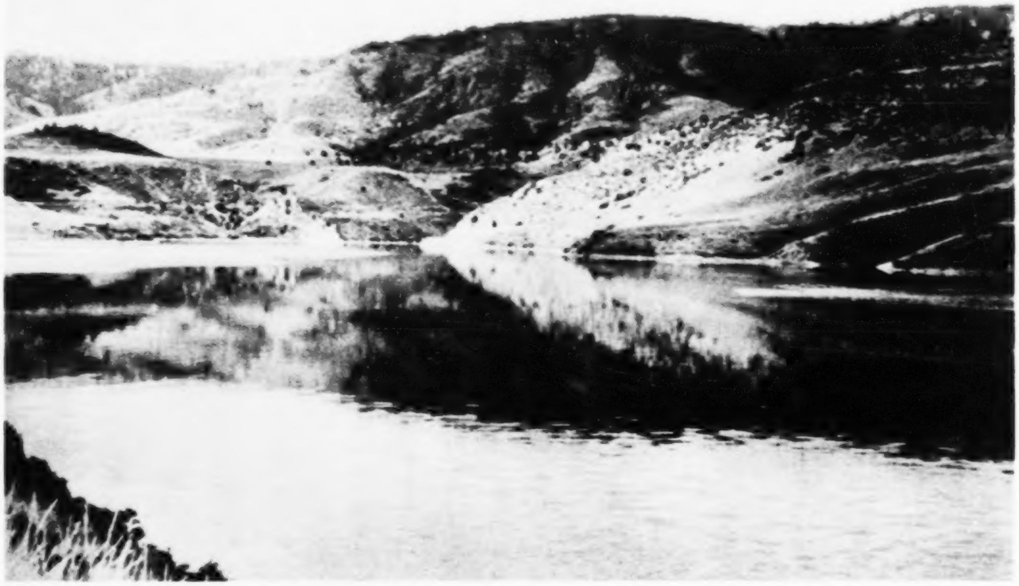

Figure II-A-2. --Ralston Creek Reservoir after treatment with hexadecanol. Note that the area covered by the monolayer appears as a dark mirror-like area in this photograph.

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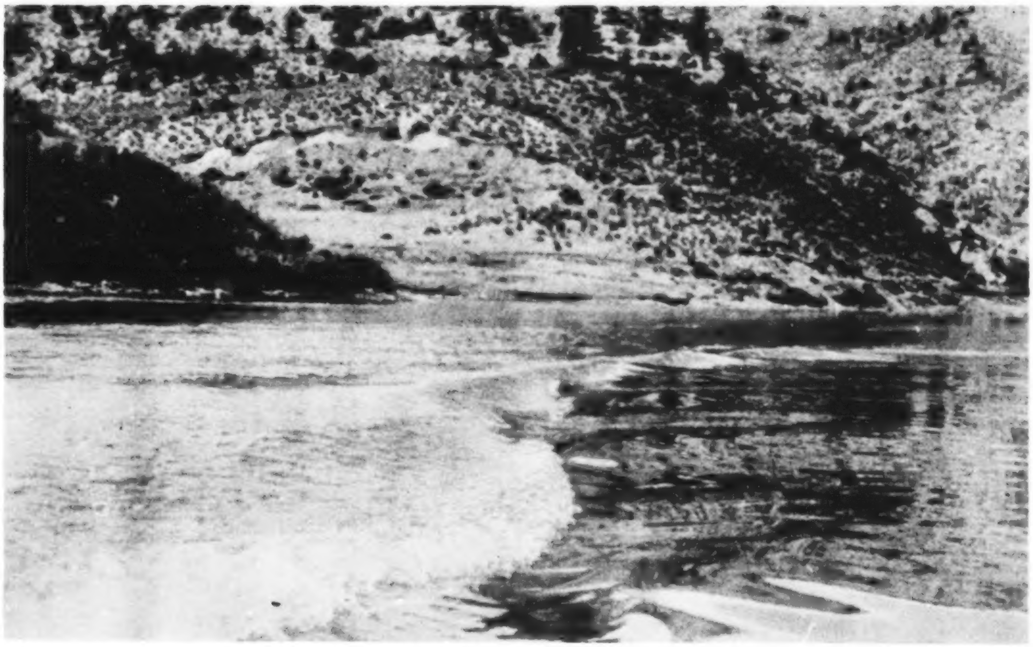

Figure II-A-3. --View from the stern of a boat traveling along the boundary of a hexadecanol monolayer on Ralston Creek Reservoir. The monolayer is on the right and the uncovered area on the left.

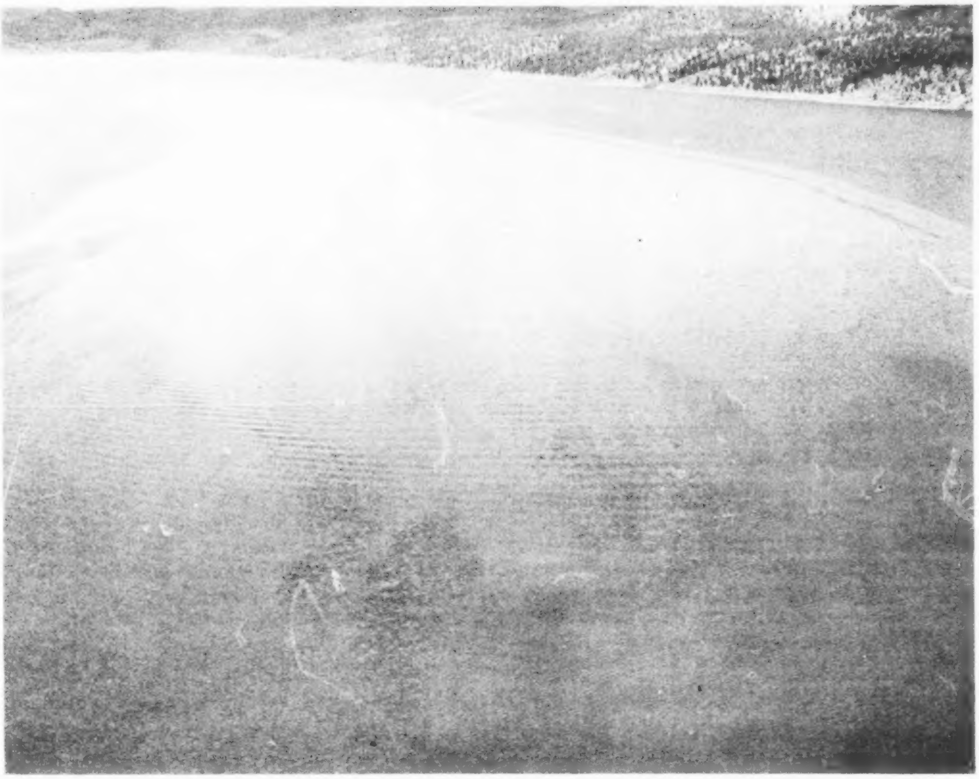

Figure II-A-4. --Aerial photograph of Carter Lake taken by the 3415th Technical Training Wing, Lowry Air Force Base. The area covered by the monolayer is the light or shiny area in middle of the lake. The double track at the right edge of the covered portion is from the two sprays on the dispensing boat, which is moving away from the camera.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Commissioner's Office--Denver	Laboratory Report No. SI-13
Division of Engineering Laboratories	Compiled by: L. O. Timblin, Jr.
Chemical Engineering Laboratories Branch	Reviewed by: W. U. Garstka
Denver, Colorado	Submitted by: W. T. Moran
June 3, 1957	

Subject: Determination of the presence and degree of compression of a monomolecular layer using indicator oils

INTRODUCTION

Involved in the study of monomolecular layers for evaporation reduction from large reservoirs is the determination of presence of the layer on the reservoir water surface and the evaluation of the film pressure. Of the many materials which have been tested for reservoir evaporation reduction, the long chain alcohols, particularly hexadecanol and possibly octadecanol, have exhibited outstanding properties. Monomolecular layers of such materials have an equilibrium film pressure of over 40 dynes per centimeter.* The ability of such films to reduce evaporation increases as the film pressure increases from zero to near 40 or 45 dynes per centimeter. Hence, to fully evaluate the condition of a film on a reservoir surface its film pressure must be known.

A Previous Technique

As the result of an early effort to devise a method of determining the presence of a monomolecular layer of hexadecanol the "talc test" was developed. In this test powdered hexadecanol and mineral talc are mixed in a 1 to 1 proportion. A small amount of this mixture is applied to the water surface and the behavior of the mixture observed. If the mixture falls on a surface devoid of a surface film, the increased film pressure in the vicinity of the mixture will result in a rapid spreading of the mixture. The hexadecanol produces the higher film pressure and the talc serves as a visual aid. If the surface is covered with a surface film whose film pressure is near 40 dynes/cm (the spreading pressure of the hexadecanol), the material simply floats on the surface where it lights.

This method gives a positive test of a compressed monomolecular layer when used in the laboratory. However, interpretation of the results from the test under field conditions is very difficult. Therefore, it is felt for field use the talc test is inadequate.

Early Studies with Indicator Oils

In 1937, Adam published the results of his work in the use of indicator oils for measuring the surface tension of seas and inland waters. In his investigations he used a series of indicator oils consisting of a solution of dodecyl alcohol in light mineral oil. The series was so formulated to provide oils with spreading pressures from 1 to 22 dynes/cm. The indicator oils described in this report are the result of an extension of Adam's work.

During his visit in April 1956, to the laboratories, Dr. Vincent Schaefer demonstrated the indicator oils he had used with Drs. K. Blodgett and I. Langmuir. These oils were used in their study of various monolayer phenomena made in the 1930's. The operation of the Schaefer Indicator Oils is based upon the production of interference colors. Each color of a given order represents a different film pressure. Such oils have been used to measure film pressures from 2 to 16 dynes/cm. Although apparently very dependable, an accurate interpretation takes a skilled and experienced observer.

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*Film pressure is defined as the difference between the surface tension of water and the surface tension of a water surface covered with a monomolecular layer.

Theory of Operation

When a drop of an indicator oil is placed upon a water surface, a duplex film is formed consisting of a monomolecular layer of the dodecyl alcohol between the oil and water phases. The spreading tendency of such a duplex film depends upon the proportion of dodecyl alcohol in the indicator oil. The larger the proportion of dodecyl alcohol the greater the spreading tendency. If a monomolecular layer is present whose film pressure is greater than the spreading pressure of the indicator oil, the oil will not form a duplex film but remain as a lens. Thus, by using a series of indicator oils with different spreading pressures, the film pressure of a monomolecular layer can be determined within the limits allowed by the different spreading pressures available in the set of indicator oils.

LABORATORY STUDIES

Procedure

The indicator oils were formulated with a light mineral oil and dodecyl alcohol $[CH_3(CH_2)_{11}OH]$. This mineral oil had the following properties: Specific gravity at 60° F. 0.815/0.825, Saybolt viscosity at 100° F. 40/48, colorless, odorless, tasteless, as supplied by the manufacturer.

The spreading pressure was measured by finding the film pressure of a monomolecular layer of hexadecanol in equilibrium with an indicator oil. A du Nouy tensiometer was used as a film balance using a clean cover glass in place of the platinum ring. The principal of the film balance is similar to that for the Harkins balance where the buoyant force of the portion of the slide under water is balanced by the downward pull of surface tension. With the du Nouy apparatus the difference of the downward pull for a clean water surface and one with a monomolecular film is measured. The film balance was calibrated using piston oils of known or measured spreading pressures.* The calibration curve is shown in Figure II-A-5.

It was necessary to measure the film pressure of a monomolecular layer rather than that of the indicator oil directly. Attempts to measure the film pressure of the indicator oils directly often gave obviously erroneous results.

The monomolecular layer of the hexadecanol was applied by allowing several drops of water from a small basket containing hexadecanol flakes to fall on the surface. Each droplet was covered with a monomolecular layer which was transferred to the water surface in the test container. An indicator oil was then applied until the monomolecular layer was just sufficiently compressed to keep the indicator oil from spreading. At this point, when the indicator oil was in equilibrium with the monomolecular layer, the film pressure of the hexadecanol layer was measured. This procedure was used to determine the spreading pressure of several indicator oils with different concentrations of dodecyl alcohol.

Results

As can be seen from Figure II-A-6 it turns out that the spreading pressure of the indicator oils is almost a logarithmic relationship with the percent dodecyl alcohol. After this relationship was established, oils with spreading pressures of 5, 10, 15, 20, 25, 30, 35, 40, and 42.5 dynes/cm were prepared and their spreading pressures checked. After standing several weeks spot checks show the oils have held their calibration well.

The calibration of the indicator oils was made at room temperature (approximately 75° F.). To check the effect of the water temperature upon the calibration, the spreading pressure of several oils was determined at various temperatures. The results are as follows:

---

*A piston oil is a liquid such as stearic acid, which will produce a monomolecular layer of a given film pressure as long as an excess of material in the form of droplets is present on the surface.

SPREADING PRESSURE, IN DYNES/CM, OF SOME INDICATOR OILS ON WATER AT VARIOUS TEMPERATURES

Rated spreading pressure, dynes/cm	Temperature, ° F.			
	40	60	80	100
5	3.5	3.5	4.9	5.6
20	18.5	--	--	20.9
35	32.3	33.2	35.6	35.4
40	36.6*	37.4	39.6	--

*At 40° F. the 40 dynes/cm indicator oil froze. The film pressure is possibly the result of a monomolecular layer of dodecyl alcohol dispersed by the solid.

It can be seen that under most field conditions the error resulting from the temperature of the water is less than about 2-1/2 dynes/cm. Since this is the error inherent in the use of a set of indicator oils prepared in steps of 5 dynes/cm and since in most cases the thermal error would be less than 2-1/2 dynes/cm, it is felt that the thermal error can be neglected for practical purposes of film detection and evaluation where a reservoir is concerned. However, if the indicator oils were to be used to determine film pressures for every dyne/cm or so, a correction for the thermal error should be established.

FIELD RESULTS

The indicator oils were used during field tests designed to develop a feasible method of applying and maintaining a monomolecular layer of hexadecanol. At the time of this writing, the first series of film application and maintenance tests had been completed. For this series of tests the indicator oils gave consistent and reasonable results. They are comparatively easy to use in the field and are felt to be reasonably accurate.

At times, field tests indicated that when testing very near a shoreline (within a few inches of the shore) a drop of oil would eventually generate, in a very small area, a monomolecular layer of dodecyl alcohol. This possible source of interference was not observed in more open water surfaces. In the field tests, it was also noted that the 42.5 and 40 dynes/cm oils would freeze in the 50° F. air and on the 40° F. water. The 35 dynes/cm oil, however, appeared to work quite satisfactorily.

ACKNOWLEDGEMENT

The author wishes to express his appreciation to Mr. Q. L. Florey, Physicist, Chemical Engineering Branch, for his help in the use of the oils under field conditions and to Mr. K. B. Goral, Physical Science Aid, Chemical Engineering Branch, for his assistance in both the laboratory and field tests.

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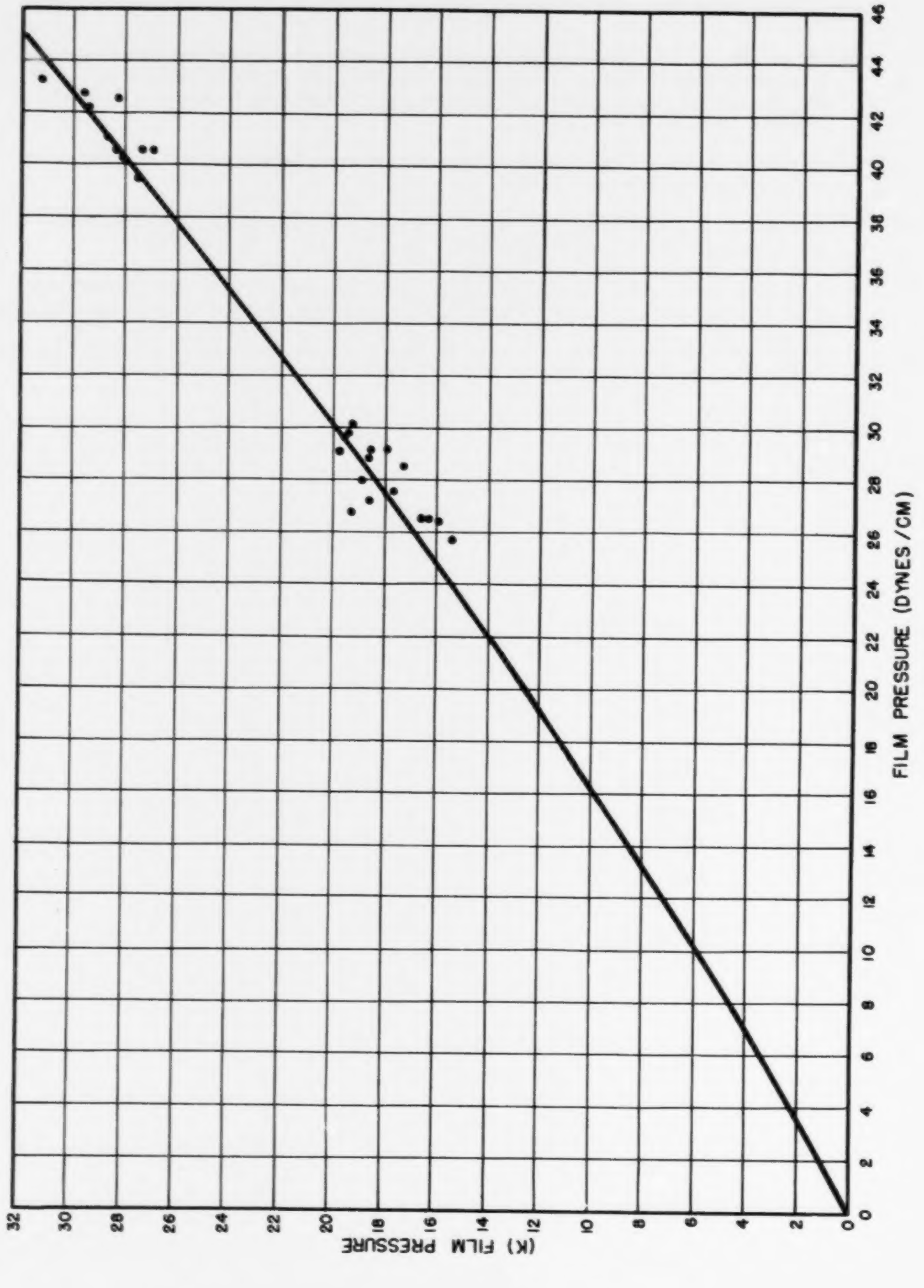

Figure II-A-5.--Calibration Curve for Film Balance.

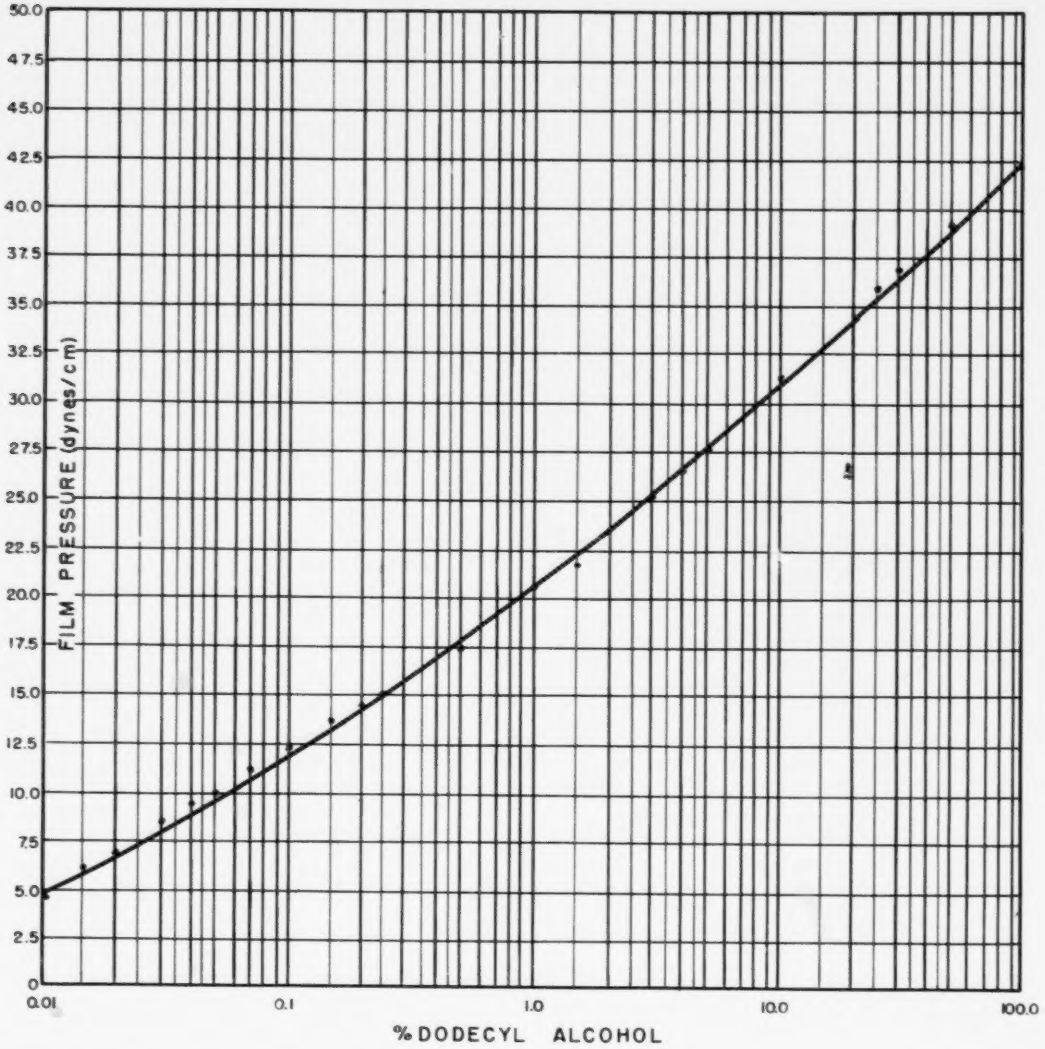

Figure II-A-6.--Film Pressure on Water vs. Percent Dodecyl Alcohol in Mineral Oil.

APPENDIX II - B

APPLICATION OF A MONOMOLECULAR LAYER

By L. O. Timblin, Q. L. Florey
and W. U. Garstka

APPLICATION OF A MONOMOLECULAR LAYER

One of the major findings of the Kids Lake studies, Appendix I, was that improved methods of film application and maintenance were needed for the Lake Hefner investigations. Although the scope of the Lake Hefner tests did not call for the ultimate in methods and equipment for film dispensing, the techniques to be employed had to be able to provide adequate film coverages for sufficient periods of time to permit the evaluation of the film's ability to reduce evaporation under field conditions.

The original concept was to employ shoreline dispensers located at strategic positions around the periphery of the lake. It was expected that, from these dispensers, hexadecanol would be applied to the lake at a rate proportional to the velocity of the offshore wind; however, the early exploratory models did not prove practical in these tests.

The first tests were at Rattlesnake Reservoir on April 17, 1957. This long, narrow lake, located in the foothills of the Rocky Mountains near Berthoud, Colorado, has an area, when full, of 100 acres. It is a part of the Bureau of Reclamation's Colorado-Big Thompson Project. Some of the outflow of Rattlesnake Reservoir at times is taken into the municipal water supply system of Loveland, Colorado.

The tests at Rattlesnake Reservoir indicated that, without a doubt, it is not practical to attempt to cover a reservoir greater than a few acres in size by using baskets of flakes, rods, or other particles of appreciable size. A special preparation of fatty alcohols cast in a 5-pound lump was also tested and found impractical. The cause of the failure of all of these methods is fundamentally the same. There is insufficient release of hexadecanol as a monolayer to keep up with the film loss.

This loss is the sum of several actions. The layer itself has a finite solubility and volatility. Using Mansfield's figures, this has been found to be about 0.08 pound per acre per day. 36/ The wind has a very pronounced effect on the film and can move the layer across the reservoir to the shore where the film collapses and may be washed upon the shore. Depending upon the lake biota, significant amounts of material may be consumed by bacterial and other living organisms. Many recognized authorities have also postulated the possibility of film loss by sunlight degradation.

Another important factor reported by several biological workers, including Ludzack and Ettinger 35/ and Hayes 34/ is the encrustation of the floating hexadecanol mass with a shell of biological life. The shell would, of course, prevent the formation of the film.

When it was found that a floating supply of solid hexadecanol was not feasible, an alternative approach was tried. This was to apply hexadecanol in such a form that the material was nearly instantly used in forming a layer. This was accomplished by dusting the surface of the lake with powdered hexadecanol. The application was made from a boat traveling across the water surface and the success of this approach was immediately evident.

Tests were then transferred to Ralston Creek Reservoir. This is a 150-acre reservoir which is part of Denver's domestic water supply system, and the tests were carried out in collaboration with the Denver Board of Water Commissioners and the USPHS. These two organizations conducted joint water quality tests during the time applications of hexadecanol were being made. The findings showed no change in the odor, taste, color, or bacterial count of the water attributable to the treatments. A progress report from the Denver Water Department on the findings with reference to water quality at Ralston Reservoir is quoted from Turre 37/:

> "At the start of the treatment of Ralston Reservoir using Hexadecanol by your department, samples of water were collected and examined by the laboratory division of the Denver Water Department. Samples were collected from the raw and effluent water at the Moffat Filter Plant. The source of water for this plant comes from Ralston Reservoir. Samples were collected and examined at the start of the Hexadecanol application on August 29th through to September 27th. Ninety-seven samples were examined for bacterial count on agar at 37° C. Tests were also made for hardness, pH value, and taste and odor. One hundred twelve samples were examined microscopically for plankton growth.
>
> "The results obtained from the above tests indicate that there were no major effects upon the water quality as a result of the Hexadecanol treatment.
>
> "We did not deem it necessary to determine the possible effects of thin films on water treatment at the Moffat Filter Plant since the water outlet at Ralston Reservoir is submerged. The possibility of surface material entering the raw water supply for the Moffat Filter Plant seems extremely remote."

During this time, over 200 pounds of hexadecanol were applied.

After several preliminary applications with powdered material, a series of tests was made to determine the amount of material required for film maintenance. Before these tests were started, no applications were made to assure that the lake was completely free of any residual film. The first application was at the rate of 0.3 pound per acre per day to establish the film. Daily applications were then made at the rate of 0.1, 0.2, and 0.4 pound per acre per day.

For the comparatively mild weather conditions which prevailed at Ralston Creek Reservoir, it was found that 0.2 to 0.4 pound per acre per day was required to maintain the maximum film coverage. Single doses of over 0.4 pound per acre per day were not advisable because insufficient quantities would remain for film replenishment, the excess material being quickly blown off to the shore.

The most efficient and effective means of film replenishment would be the continuous application of appropriate amounts of materials. Daily applications at one time often would result in over 90 percent of the lake covered with a fully compressed film, as shown on Figure II-B-1. However, the following day the coverage had dropped to 50 percent or less.

On many occasions, it was found that mild breezes had compressed the layer to film pressures higher than the equilibrium spreading pressure of the hexadecanol product being tested. At temperatures as low as 41° F., film pressures of 40 d/cm were found. At this temperature and for this material, the equilibrium spreading pressure has been found to be about 25 dynes/cm. The spreading pressure was determined by measuring the equilibrium film pressure produced by a 4-cm cake floating in a 12-cm dish of water. The spreading pressure was found to be a function of temperature, as shown in Figure II-B-2.

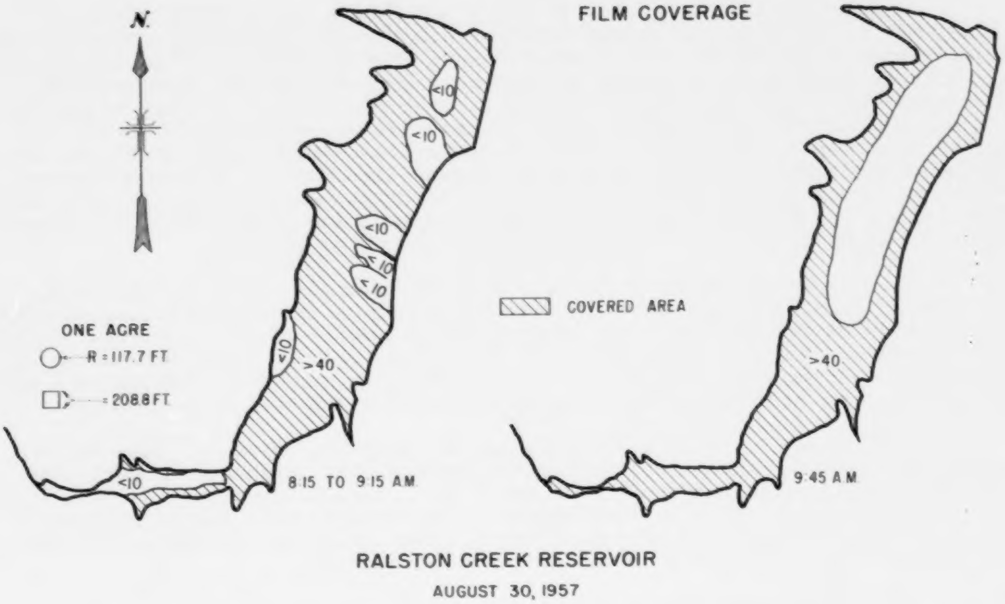
N.
FILM COVERAGE
<10
<10
<10
<10
<10
<10
>40
<10
8:15 TO 9:15 AM
ONE ACRE
R = 117.7 FT
= 208.8 FT
COVERED AREA
>40
9:45 AM
RALSTON CREEK RESERVOIR
AUGUST 30, 1957

Figure II-B-1. --Treatment: Powdered Combination of Fatty Alcohols No. 1.

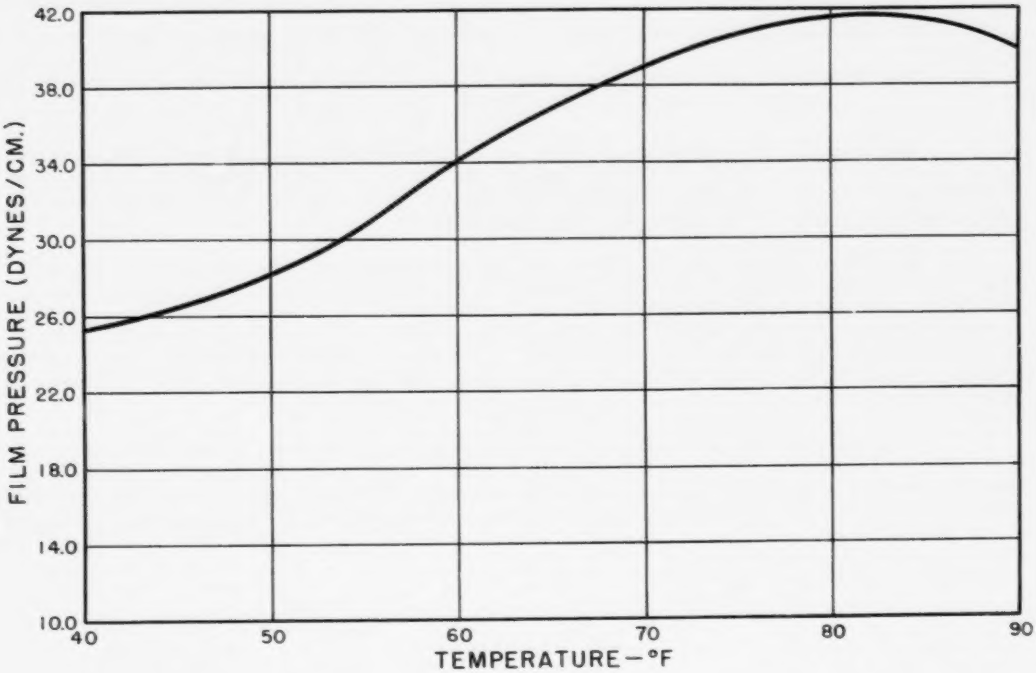

Figure II-B-2. --Spreading Pressure vs. Temperature for Fatty Alcohol No. 1.

It was found that Rattlesnake Reservoir and Ralston Creek Reservoir were usually free of any monolayer except that which was applied. Apparently, there was sufficient wind and exchange of water to prevent much of an accumulation of a biological film. Occasionally, however, such biological films were apparently present with moderate film pressures. Hayes 34/, pages 4 through 6, gives an informative review of the literature on naturally occurring surface films. These could be distinguished from the fatty alcohol monolayer by the pattern of the spreading indicator oil of higher pressure. The fatty alcohol monolayer behaves like a 2-dimensional liquid and the spreading indicator oil takes a curved pattern usually approximately circular. However, the biological films behave like a 2-dimensional solid and the spreading indicator oil takes on a star-shaped pattern or an irregular shape bounded by a series of straight lines.

During the 1957 field studies, it became increasingly evident that the use of powdered material, although very effective in producing the film, presented some definite problems of handling and dispensing. With a melting point of only about 125° F., the powder has a great tendency to lump and cake. The obvious solution to this problem is the separation of the particles with some inert material. Dry materials, although they may prove feasible in the future, did not present an immediate solution to the problem.

Another approach was to use water as the separating material. Because the hexadecanol is lighter than water, the mixture tends to separate into two phases. Considerable laboratory tests by the Bureau and by the manufacturers were carried out during the fall and winter of 1957. Many promising formulations were developed but none could meet all of the requirements necessary to assure adequate coverage of Lake Hefner. Some of the required properties of an aqueous preparation are:

(1) It should have long term stability.

(2) The viscosity should be relatively constant.

(3) The ability of the monolayer to reduce evaporation should remain unimpaired.

(4) The hexadecanol should not mix with the lake water when applied.

(5) The preparation should not introduce undesirable chemicals into the lake water as determined by the USPHS.

Although the development of satisfactory noncaking dry mixtures or acceptable aqueous preparations is still to be accomplished, the use of such materials in automatic dispensing devices strategically located near the shoreline appear to be one of the most efficient and effective techniques for film maintenance.

However, faced with the unavailability of hexadecanol in suitable form for automatic dispensing, the method of maintaining the film by continuous applications from a boat was explored and developed for use at Lake Hefner. The basis of this method is to mix dry powder with lake water just prior to application. The mixture is stabilized by continuous mixing. The mixing is done with gas power-driven propellors in two 55-gallon drums located on the boat. As the boat travels across the lake surface, the mixture is sprayed out and forms a layer soon after striking the water surface.

A prototype (Figure II-B-3) was built and tested at Carter Lake, Colorado. It was clearly demonstrated in the tests on this 1,000-acre lake, as shown in Figure II-A-4, that the method was feasible for use at Lake Hefner. The feasibility and uniqueness of this method was recognized and a public patent for the method is being pursued by the U. S. Government.

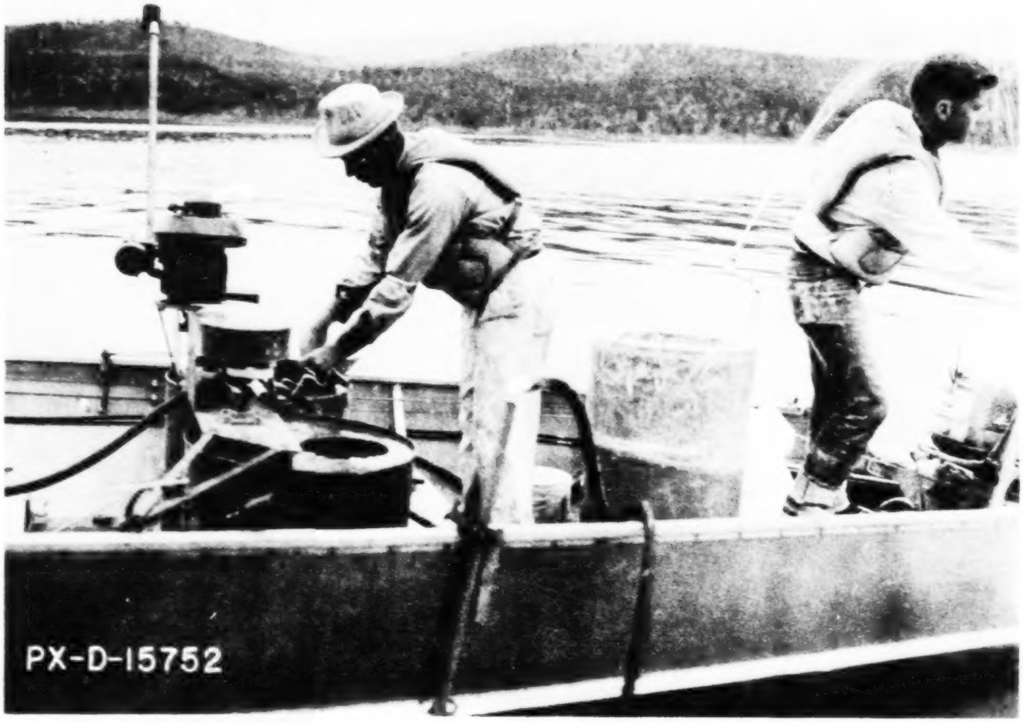

Figure II-B-3. --Photograph of the boat-mounted dispensing equipment taken during preliminary tests conducted at Carter Lake near Loveland, Colorado. This equipment was later used at Lake Hefner.

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APPENDIX II - C

SCREENING TESTS

By Q. L. Florey and L. O. Timblin, Jr.

SCREENING TESTS

Extensive screening tests were initiated in 1955 to study the evaporation reduction of hexadecanol and other monolayer forming materials. 40/ These tests were usually performed out-of-doors in 4-foot-diameter pans (U. S. Weather Bureau class "A" evaporation pans). In these tests, hexadecanol was one of the best performers.

During the 1956 screening tests with various forms of hexadecanol, it was observed that under identical conditions the material in the form of small beads effected a smaller reduction of evaporation than did an equal weight of material in flake form. This is contrary to what would be expected, as the ability to produce a monomolecular layer is a function of the wetted perimeter. The beaded material, having a larger perimeter, would be expected to have a larger wetted perimeter.

A photographic and analytical study was made to investigate the flotation of the flakes and beads. 39/ Photographs were taken of the beaded material which showed that for such small spheres, surface tension is sufficient to pull the particle almost completely under the water; Figure II-C-1.

A mathematical analysis of the forces on a floating sphere was made, and an approximate approach to a solution of the problem carried out. For the approximate solution, it was assumed that the bead was held in a position where the freeboard, neglecting surface tension, was reduced by one-half. Then taking into account surface tension, the forces were analyzed to see if the bead would tend to rise or sink when released.

The analytical approach showed that as the size of a floating bead of hexadecanol decreases, the effect of surface tension increases. This causes the wetted perimeter of small particles to be disproportionately small. The effect surface tension has upon the bead is shown in Figure II-C-2.

In considering a broadcast type of application where hexadecanol would simply be cast upon the surface of a reservoir, the most efficient application would be with a form of hexadecanol giving the largest wetted perimeter per unit weight. These studies indicated a finely divided material may not have the largest wetted perimeter for unit weight. Rather, there is probably an optimum size which could best be determined experimentally; from the results of the analytical approach, it was estimated that the optimum size would be in the range of 1/2- to 2-mm diameter.

However, it was recognized that for extremely finely divided powdered material the effect of surface tension may be overridden by the vast increase in the number of particles per unit weight. This was confirmed by later field tests.

Two different series of indoor tests, with class "A" evaporation pans, were carried out with only limited success. 38/ One was conducted in rooms with constantly moving air, the temperature of which could be precisely controlled. The purpose of this test was to determine the effect of temperature on the performance of the film, as previous screening test results had indicated that temperature might be an important variable. These tests were unsuccessful, probably because of dust in the air which interfered with the film.

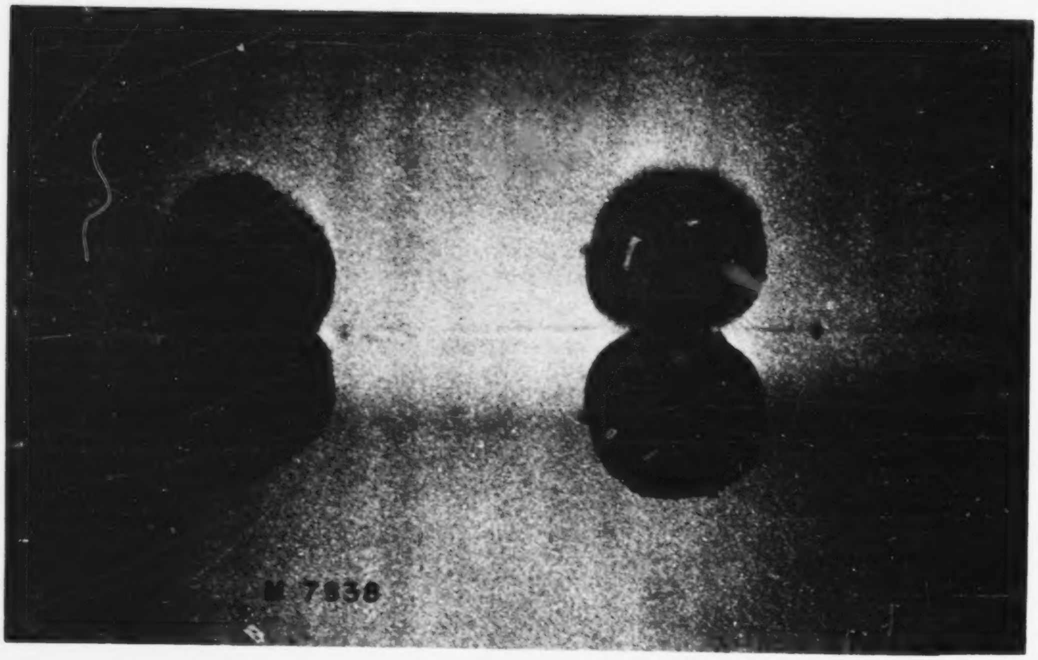


Figure II-C-1a. --Composition of Fatty Alcohols Used in Screening Tests.

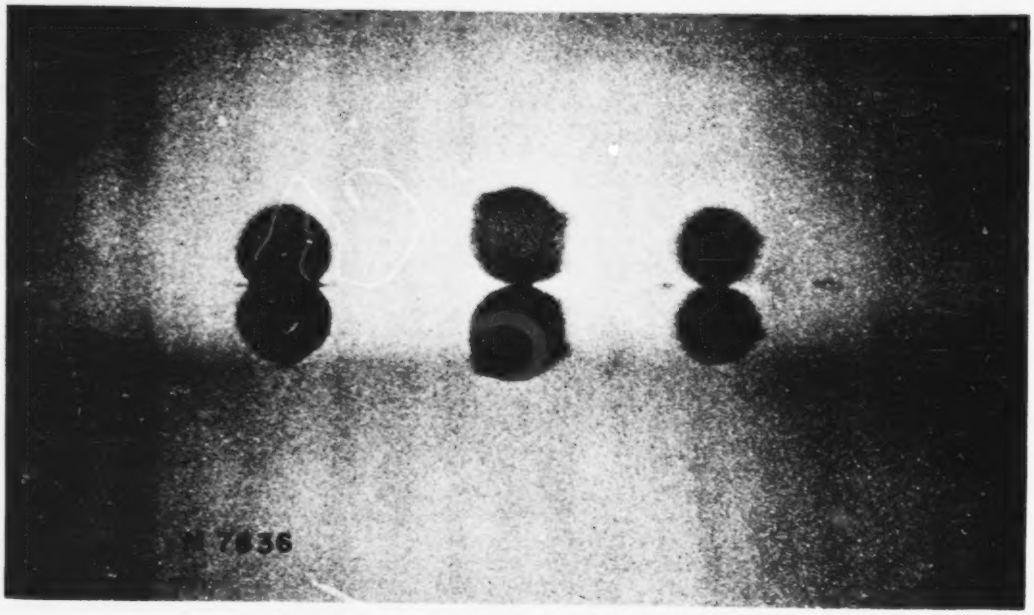
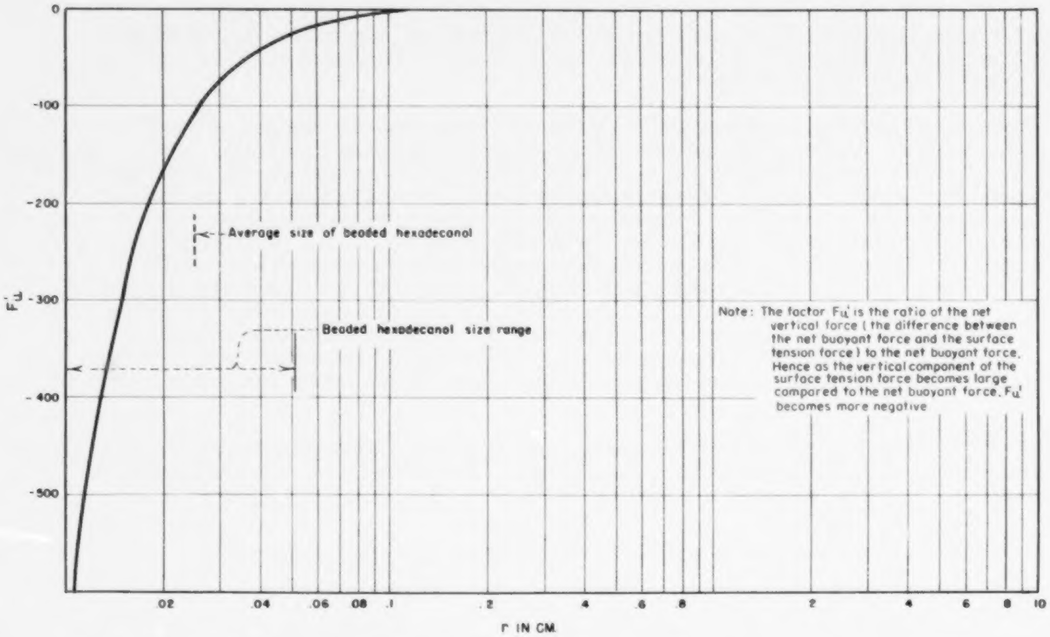


Figure II-C-1b. --Photographs taken of beads of hexadecanol floating on the water surface. As the point of view is slightly below the waterline, both the portion of the bead below the water and its reflection are seen. Some of the beads were lightly placed on the surface while others were submerged before photographing. Note that many of the beads float nearly completely under water. These are the beads which were initially submerged.



Note: The factor F_u' is the ratio of the net vertical force (the difference between the net buoyant force and the surface tension force) to the net buoyant force. Hence as the vertical component of the surface tension force becomes large compared to the net buoyant force, F_u' becomes more negative

Figure II-C-2. --The Effect of Surface Tension Upon the Flotation of a Sphere of Hexadecanol.

Rather than reduce the size of the test vessel to where the contamination problem could be controlled in the laboratory, it was decided to conduct the tests out-of-doors and depend upon the seasonal changes of ambient temperature for different temperature. These tests were conducted during the summer of 1958, concurrently with the Lake Hefner tests. Twenty-two selected fatty alcohol mixtures were tested. This included Fatty Alcohol No. 1, which had been previously chosen for the Lake Hefner tests. For this material, the temperature correlation tests were doubly important because the evaporation reduction factor of the material had to be known for the water temperatures at Lake Hefner during the tests to permit a thorough evaluation of the field performance of the film.

With the exception of cetyl alcohol (practical) and Fatty Alcohol No. 29, all of the fatty alcohols represent commercially available products produced from natural raw materials. The cetyl alcohol (practical) is practical grade hexadecanol, and is included in all of our screening tests as a standard. Fatty Alcohol No. 29 is synthesized from petroleum, and is a pilot plant product. The screening tests were conducted for 2-week intervals, but only the results for the first 24 hours after treatment are reported here. This period was chosen because the field tests, including those at Lake Hefner, showed the persistence of the film under field conditions was in the order of 24 hours. If, during the temperature correlation screening tests, precipitation occurred within 24 hours after treatment, the evaporation savings during the next 24 hours for which data were available were taken for the results of that particular test. This was deemed necessary to eliminate any errors or unusual effects that might be caused by the precipitation, and a 24-hour period was required to obtain sufficiently accurate measurements of evaporation. This procedure, however, produces data obtained by a slightly different procedure for tests with and without precipitation.

For the temperature correlation tests, the average temperature is a time-weighed average of measurements of water temperature taken approximately at 8 a.m., 3:30 p.m., and the following 8 a.m.

The results of these tests are shown in Figure II-C-4, and the composition of the different materials is given in Table II-C-1. Straight lines, estimated to best fit the data, are shown in the figure. The estimated straight line for Fatty Alcohol No. 1 is also shown in greater detail in Figure II-C-3.

Several interesting observations can be made concerning the results of these tests. Of the 22 fatty alcohol combinations, all chosen as promising materials, Fatty Alcohol No. 1 has a relative standing, in decreasing order of effectiveness, of 15 out of 22. This standing is based upon the evaporation reduction factor at 82.5° F., the highest temperature of the test. Therefore, 14 other materials have now been found superior to the hexadecanol product used at Lake Hefner. The best three materials, at the highest temperature, all were about 1.5 times as effective as the material used at Lake Hefner. There is no apparent clear-cut relationship between the performance of the materials and the percent composition of the fatty alcohol constituents of the mixture; several mixtures of similar compositions have different performances. It has been postulated that both the raw material and manufacturing process may be related to the products' performance. These and other findings of these screening tests are under further study and experimentation.

For Fatty Alcohol No. 1, least squares lines have been computed using both data from days without precipitation and with precipitation. The differences in the evaporation savings between computations using the estimated line and using the least squares lines are shown in the following table:

Analysis	Film evaporation efficiency	Percent difference in estimated evaporation savings
Estimated line	0.395	--
Least squares excluding ppt	0.386	2.3
Least squares including ppt	0.405	2.5

This difference was determined for a water surface temperature of 26° C. (68.8° F.), which is typical of the field condition prevailing during the Lake Hefner tests.

Since the evaporation reduction factor was determined by comparing the evaporation of treated and control pans, the use of a pan coefficient, which attempts to convert pan evaporation to lake evaporation, was not pertinent. Therefore, pan coefficients were not applied.

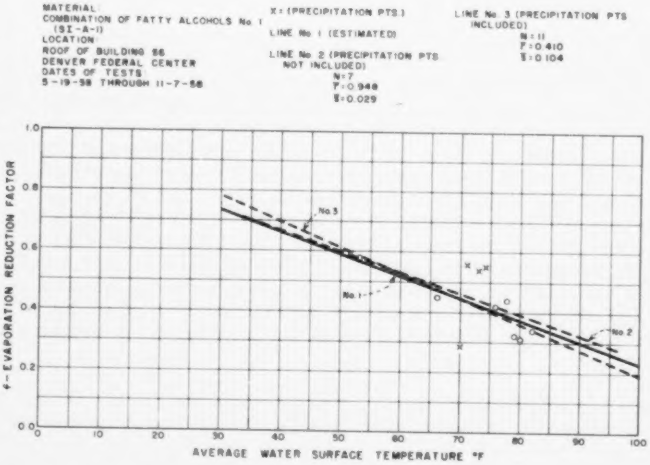


Figure II-C-3. --Evaporation-Water Temperature Correlation for First 24 Hours (Lake Hefner-1958).

Table II-c-1

COMPOSITION OF FATTY ALCOHOLS USED IN SCREENING TESTS

Fatty Alcohol No.	Composition*
28	C_{14} = 10.0%; C_{16} = 30.0%; C_{18} = 57.0%; uns C_{18} = 3%
4	C_{14} = 0.15%; C_{16} = 8.8%; C_{17} = 2.0%; C_{18} = 72.3%; C_{19} = 1.6%; C_{20} = 10.0%; C_{21} = 1.9%; C_{22} = 3.3%
12	Commercial stearyl alcohol
26	C_{16} = 1.0%; C_{18} = 99.0%
3	C_{10} = 0.15%; C_{12} = 0.4%; C_{14} = 3.8%; C_{15} = 0.35%; C_{16} = 24.9%; C_{17} = 1.9%; C_{18} = 59.2%; C_{20} = 5.0%; C_{21} = 0.8%; C_{22} = 1.0%
27	--
18	C_{14} = 2.0%; C_{16} = 95%; C_{18} = 3.0%
29	Commercial cetyl alcohol
11	Commercial cetyl alcohol
17	C_{14} = 1.8%; C_{16} = 65.3%; C_{18} = 29.0%; C_{20} = 3.9%
16	--
Cetyl alcohol (pract)	C_{16} = 95%
7	Commercial stearyl alcohol
2	C_{12} = 0.1%; C_{14} = 3.7%; C_{15} = 0.6%; C_{16} = 42.6%; C_{17} = 3.2%; C_{18} = 41.7%; C_{19} = 2.9%; C_{20} = 5.1%
1	C_{12} = 1.0%; C_{14} = 4.0%; C_{16} = 93%; C_{18} = 2%
15	C_{16} = 25.0% uns; C_{18} = 66.0% uns; C_{18} = 1.0% sat; (C_{14}, C_{20}, C_{22}) = 8.0% uns
14	C_{14} = 1% sat; C_{14} = 1% uns; C_{16} = 25.0% sat; 5.0% uns; C_{18} = 5.0% sat; C_{18} = 62.0% uns
8	--
25	C_{12} = 0.1%; C_{14} = 1.7%; C_{16} = 98.0%; C_{18} = 0.2%
13	C_{14} = 2% sat; C_{14} = 2% uns; C_{16} = 30.0% sat; C_{16} = 5.0% uns; C_{18} = 5.0% sat; C_{18} = 50.0% uns
9	Commercial cetyl alcohol; C_{16} over 90%
10	Commercial myristyl alcohol

*Unless otherwise stated the percent composition is for the saturated fatty alcohol.

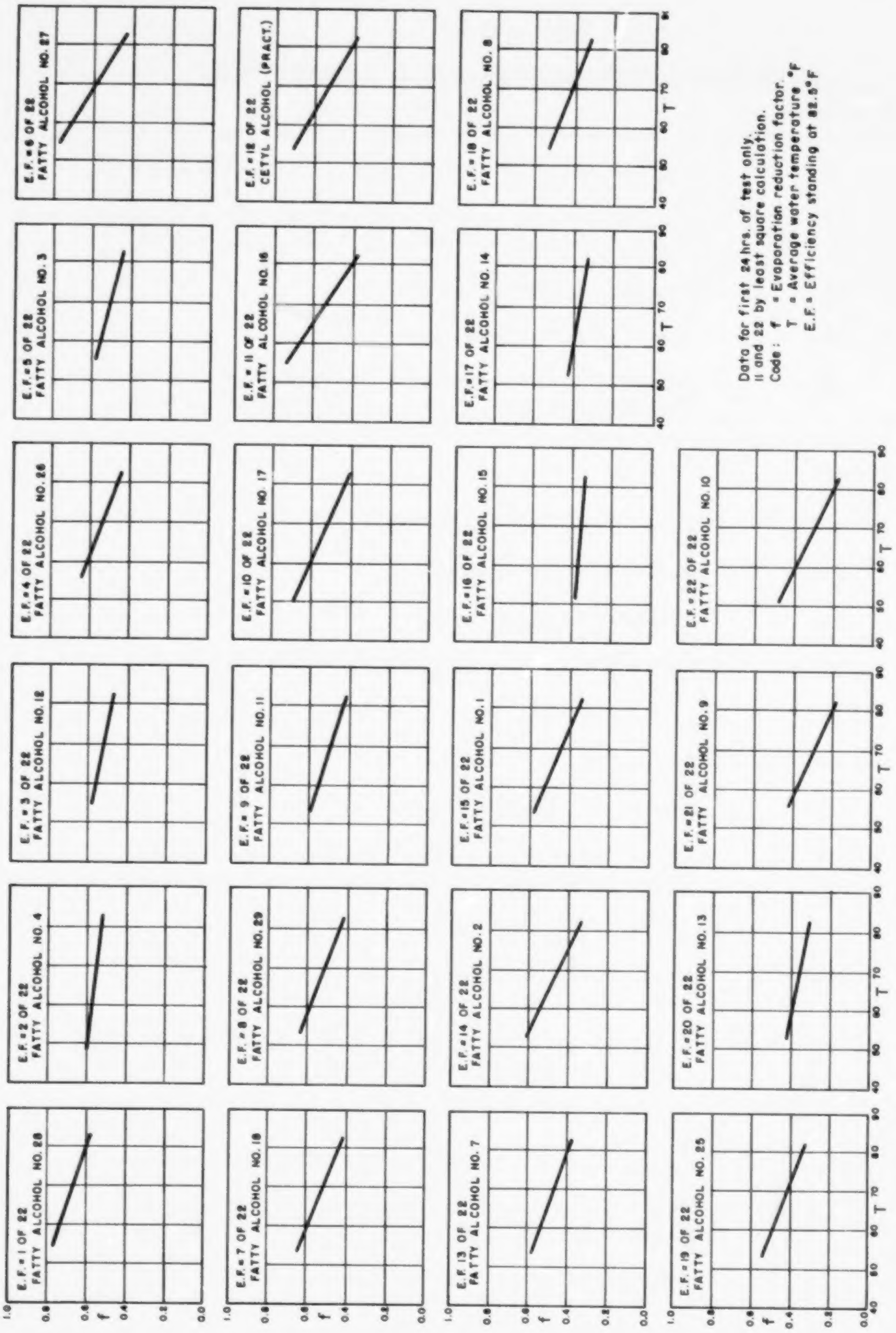


Figure II-C-4. --Evaporation-Water Temperature Correlation for Several Combinations of Fatty Alcohols.

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